Coastal Erosion and Accretion of Beaches - The Effect of Storm Duration, Water Levels and Long Waves on Selected Numerical Models

by
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ABSTRACT

Varying water levels, storm duration and long waves all have a significant impact on cross-shore beach profile development. Although it is generally known that these parameters have an impact on beach profile development, little research have been done to identify the specific effects of these parameters on cross-shore beach profile development. Furthermore, it is not clear whether numerical models can be used to predict the individual effects of these parameters on cross-shore beach profiles.

Data specific to varying water levels, storm durations and long waves were obtained and analysed to gain an understanding of the effect of these parameters on cross-shore beach profile responses. Three cross-shore sediment transport and morphology models (SBEACH, XBEACH and DUNERULE) were selected and their sensitivity to varying water levels, storm durations and long waves were analysed. The physical scenarios were then modelled in SBEACH, XBEACH and DUNERULE to assess whether any or all of the models could be used to predict accurate beach profile responses under the impact of the studied parameters.

Although DUNERULE is sensitive to different water levels, it does not have the ability to model scenarios where water level varies throughout the impact period. Neither SBEACH nor XBEACH predicted consistent beach profile responses under varying water levels, but SBEACH did perform marginally better than XBEACH. It was found that the impact of storms with different durations was well predicted by SBEACH, XBEACH and DUNERULE. Free long waves were only modelled in SBEACH and XBEACH and the results indicated inaccurate predictions from both models. XBEACH was the only model that could predict cross-shore beach profile response under bichromatic wave conditions, but these predictions proved to be inaccurate. It was noted that none of the models predicted accretive conditions when the physical data indicated that sediment accretion occurred.

It is recommended to assess the model accuracies based on field data (instead of just flume data) for further studies. More prototype flume experiments should be done on the effect of long waves on cross-shore beach profile responses during storm conditions. In order to obtain better XBEACH model results, extensive model calibration should be done.

OPSOMMING

Wisselende watervlakke, stormduurtes en lang golwe het 'n beduidende impak op dwarssnitprofieldie strandprofiel-ontwikkeling. Alhoewel dit algemeen bekend is dat hierdie parameters 'n impak op die ontwikkeling van strandprofiele het, is daar tot op hede min navorsing gedoen om die spesifieke gevolge van hierdie parameters op strandprofiele te identifiseer. Verder is dit nie duidelik of numeriese modelle gebruik kan word om die ondeskeie invloede van hierdie parameters op strandprofiele te bepaal nie.

Data, spesifiek van toepassing op wisselende watervlakke, stormduurtes en lang golwe is ingesamel en ontleed om 'n begrip van die effek van hierdie parameters op strandprofiele te kry. Drie sedimentvervoer en morfologie modelle (SBEACH, XBEACH en DUNERULE) is gekies en hul sensitiwiteit teenoor verskillende watervlakke, stormduurtes en lang golwe is ontleed. Die fisiese data was in SBEACH, XBEACH en DUNERULE gemodelleer om te bepaal of enige van of al die modelle gebruik kan word om akkurate strandprofiel-ontwikkeling, onder die invloed van die bogenoemde parameters, te voorspel.

DUNERULE is sensitief vir verskillende watervlakke, maar het nie die vermoë om gevalle te modelleer waar watervlakwisseling voortdurend plaasvind nie. Nie SBEACH of XBEACH het konsekwent strandprofiele gemodelleer onder wisselende watervlakke nie, maar die voorspellings van SBEACH was effens beter as dié van XBEACH. Daar is bevind dat die impak van storms met verskillende duurtes goed voorspel is deur SBEACH, XBEACH en DUNERULE. Vry lang golwe kon slegs deur SBEACH en XBEACH gemodelleer word en die resultate dui daarop dat beide modelle strandprofiel-ontwikkeling onakkuraat voorspel. XBEACH is die enigste model wat strandprofiel-reaksies onder bichromatiese golftoestande kon voorspel, maar uit die resultate blyk dit dat die voorspellings onakkuraat is. Daar was opgemerk dat nie een van die modelle die opbou van strande voorspel het, wanneer sediment opbouing in werklikhid, volgens die fisiese data plaasgevind het nie.

Dit word aanbeveel dat daar in die toekoms ook velddata (in plaas van slegs laboratorium kanaal-data) gebruik word om die akkuraatheid van die modelle te assesseer. Meer prototipe kanaal-eksperimente moet gedoen word om die uitwerking van lang golwe op strandprofiele tydens storms beter te verstaan. Ten einde beter XBEACH model resultate te verkry, moet 'n uitgebreide model kalibrasie gedoen word.

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B	Dune Elevation	m
c	Wave Celerity	m/s
C	Concentration	mg/m^3
C_D	Drag Coefficient	-
D	Wave Energy Dissipation	Nm/s
d	Sediment Grain Size	mm
f	Frequency	Hz
F, F_s	Wave Energy Flux	N/s
$F_{g,\ b,\ D}$	Force	N
g	Gravitational Acceleration	m/s^2
H	Wave Height	m
h	Water Depth	m
K	Empirical Transport Rate Coefficient	m^4/N
L	Wave Length	m
ɲ	Wave Set-up	m
q	Sediment Transport Rate	$m^3/m/s$
R	Shoreline Recession	m
Re	Reynolds Number	-
S	Sea Level Rise	m
S_p	Shape Factor	-
S_{xx}	Radiation Stress Component	J/m^2
T	Wave Period	s
V	Volume	m^3
v	Velocity	m/s
w	Sediment Fall Velocity	m/s
ε	Transport Rate Coefficient for Slope Dependent Term	m^2/s
θ	Wave Angle	°
κ	Empirical Wave Decay Coefficient	-

λ	Spatial Decay Coefficient	1/m
ρ	Density	kg/m^3
ν	Kinematic Viscosity	m^2/s

1 INTRODUCTION

1.1 BACKGROUND

Coastal erosion and accretion are dynamic processes that occur along all coasts worldwide. These processes cause the shoreline to change continuously and are driven by the movement of wind and water. The severity of coastal erosion and accretion thus largely depends on the sediment properties, wind characteristics and surf zone hydrodynamics.

Beaches are more prone to severe erosion or accretion than rocky shores because of the ease with which beach sediment can move. This implies that beach profiles can change sporadically and drastically when there is a change in environmental conditions due to, for example a storm. Severe changes to beach profiles could lead to structural damage if structures are built within the affected area. It is therefore important to be able to predict the extreme cases of coastal erosion and accretion in order to design solutions to protect current structures that might be affected and to plan properly for future coastal developments.

Numerous field studies have been conducted on beach profile changes due to erosion and accretion. These field studies, along with knowledge gained from laboratory models, have been analysed in order to create numerical models. The numerical models can be used to assist in the prediction of coastal erosion and accretion of beaches.

Some research has been conducted on the influence of storm duration, water level and long waves (or wave groups) on coastal erosion and accretion of beaches. From this research, there is a general understanding that a longer storm duration will cause more erosion or accretion of beaches than shorter storm durations, an increase in water level will typically lead to an increase in coastal erosion and accretion and long waves most probably lead to changes in beach profiles. Yet, there is little information available on the quantification of the amount of erosion and accretion caused by the above-mentioned aspects.

1.2 PROBLEM STATEMENT

Coastal engineers have the responsibility to not only design structures that are safe from coastal erosion or accretion, but also to find solutions to protect current structures from damage caused by coastal erosion and accretion. In order for the engineers to be successful in fulfilling their responsibilities, they have to understand how different factors contribute to coastal erosion and accretion.

In this study, it was necessary to evaluate the effect of water level variation, storm duration and long waves on cross-shore beach profile evolution by analysing available physical data. Since numerical models are often used to assist engineers to solve problems, the sensitivity and quantitative accuracy of some numerical models in predicting cross-shore beach profile response (erosion and accretion) to water level variation, storm duration and long waves were studied.

1.3 Objective

The objective of this study was to determine the impact of water level variation, storm duration and long waves on cross-shore beach profile evolution. Furthermore, it was necessary to conclude whether selected numerical cross-shore sediment transport models can be used to quantify the effects of storm duration, water levels and long waves on cross-shore beach profiles. The objective was reached through completion of the following steps:

- Research was conducted on previous studies in this field.
- Prototype and field data on beach profile change were obtained.
- Three numerical cross-shore sediment transport models were selected and their sensitivity to changing water levels, storm duration and long waves were analysed.
- Physical data on coastal erosion and accretion were analysed and compared to numerical data obtained from beach profile numerical models.
- From the selected numerical models, the most accurate numerical model was identified for the quantitative prediction of cross-shore beach profile changes due to the effects of storm duration, water level variation and long waves respectively.

1.4 Scope and Limitations

In this study only the effects of storm duration, water levels and long waves on cross-shore sediment transport were analysed. It was assumed that longshore sediment transport was absent or constant and thus negligible in this study.

The physical data were restricted to large wave tank and field data in order to neglect the effect of scaling. The effect of scaling was not investigated.

The numerical models that were studied were limited to SBEACH, XBEACH and DUNERULE. The latest non-hydrostatic XBEACH model was not included in this study.

1.5 Thesis Layout

The first chapter in this thesis provides background information on the study theme along with a problem statement, objective and a brief discussion of the steps that were followed to reach the objective. The scope and limitations of the study were also discussed in this chapter.

Chapter 2 is a review of the literature related to the study. In this section, emphasis was specifically placed on coastal processes and their impact on cross-shore beach erosion and accretion.

The methodology followed in this study was discussed in the third chapter. Firstly, an overview of the research methodology was provided, after which more attention was given to methods used to evaluate and assess the numerical models' sensitivity and accuracy respectively.

In Chapter 4, the data that were obtained and employed in this study are discussed.

An overview of the selection process of the numerical models that were studied is provided in Chapter 5. The background theory and model set-up of the selected models were briefly discussed, followed by detailed model set-up used for the model sensitivity evaluations and assessment of the model accuracies.

In the sixth chapter, the sensitivity of the selected numerical models to varying water levels, different storm durations and long waves were analysed and discussed.

The assessment of the accuracy of the selected numerical models in quantifying beach profile response due to varying water levels, storm duration and long waves are given in Chapter 7.

Chapter 8 concludes the study by emphasizing the key findings and providing recommendations for future studies.

The thesis was ended with a list of references.

2 LITERATURE REVIEW

2.1 OVERVIEW

In this section an overview will be given on relevant literature applicable to the study of the effects of storm duration, water levels and long waves on coastal erosion and accretion. The following themes are included in this chapter: Coastal zones, cross-shore beach profiles, sediment properties and the interaction between the surf zone hydrodynamics and cross-shore beach profiles. The intention of the literature review was to gain a holistic understanding of cross-shore sediment transport and the effects of storm duration, water levels and long waves on cross-shore beach profiles. The literature review of the cross-shore sediment models was not included in this chapter, but is provided in Section 5.

2.2 COASTAL ZONES

The boundary between land and a large water body is referred to as the shoreline. “Coastline” is a more specific term for the boundary between land and sea (ocean). The area surrounding the shoreline that is affected by land-sea interactions is known as the coastal zone. The coastal zone is a dynamic area that changes constantly due to the impact of environmental factors such as wind and waves. Different coastal zones exist due to differences in geomorphology, environmental conditions, *et cetera*. Some of the main coastal zones that occur around the world are summarised in Table 2-1.

Table 2-1: Classification of Coastal Zones (Coast and Shoreline Processes, 2016)

Coastal Zone		Characteristics	Image
Submergence	Ria Coast	Formed due to melting ice	
	Fiord Coast	U-shaped glacial troughs	
	Dalmatian Coast	Mountains parallel to longitudinal coast	
	Estuarine Coast	Drowned river mouths	
Emergence	Uplifted Lowland Coast	Uplifted continental shelf; produces beaches, dunes, lagoons and salt marshes	
	Emergent Upland Coast	Raised coastal plateau; produces raised beaches and steep cliffs	

2.3 Cross-shore Beach Profiles

Coastal zones with large amounts of fine loose sediment often experience the most erosion and accretion. These coastal zones are typically sandy beaches that occur at uplifted lowland coasts and may be divided into numerous sub-zones as shown in Figure 2-1.

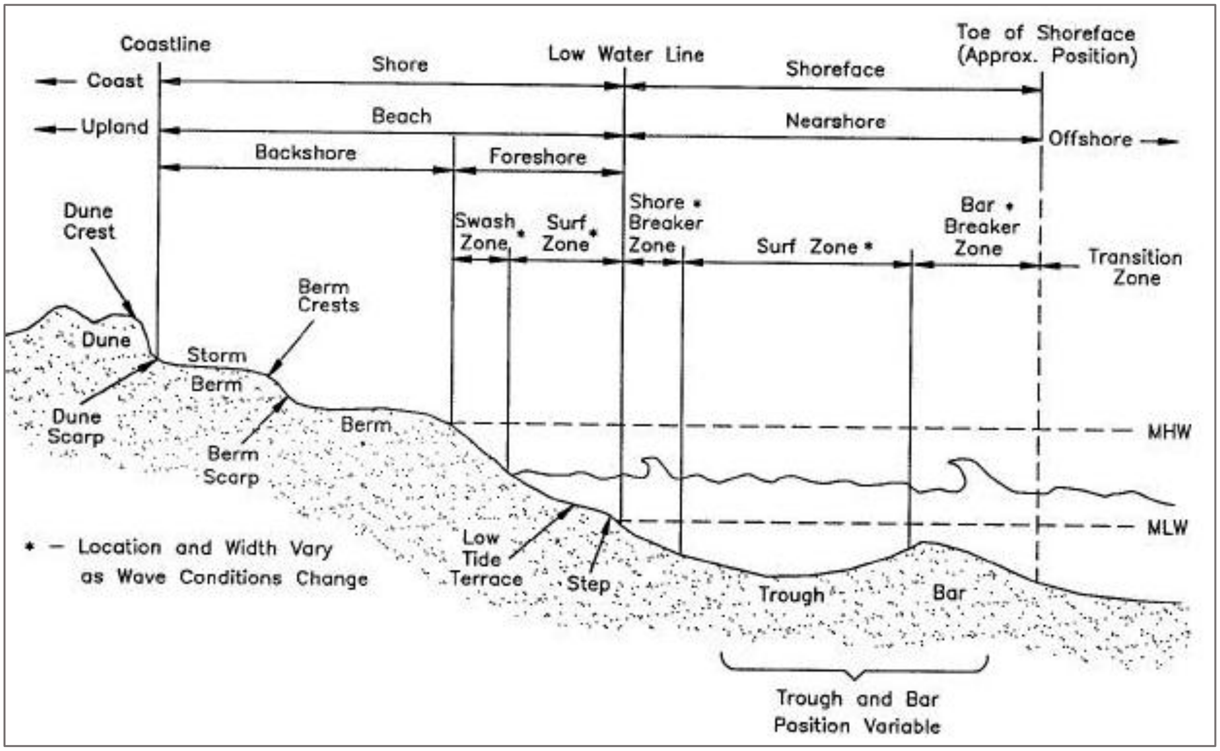


Figure 2-1: Sub-zones within the coastal zone of a beach (U.S. Army Corps of Engineers, 2003)

The profile of the beach given in Figure 2-1 is identified as the cross-shore beach profile. Cross-shore beach profiles change continuously due to active and passive factors (Gourlay, 1980). Active factors influencing cross-shore beach profile shape include waves, tides, winds, rainfall, temperature and the duration of these factors. Passive factors that influence cross-shore beach profile shapes are beach material, initial cross-shore profile shape and the geology of the area.

The changes that occur due to the above-mentioned factors are often negligible on a larger scale. However, significant changes such as the shift of the bar, step and berm depends on the season and the accompanying wave and wind conditions. When strong seaward flow occurs near the seabed (typically during storms), offshore sand bars move seaward (Thornton *et al.*, 1996). During summer periods when cross-shore currents are weaker and wave orbital velocities are still relatively big, offshore sandbars migrate landward (Elgar *et al.*, 2001).

Theoretically, an equilibrium beach profile may exist when wind and wave conditions and thus wave energy, remain constant. The concept of an equilibrium beach profile is not feasible in reality, since wind and wave conditions vary constantly. Theoretical beach profiles can, however, still be used to predict the expected beach profile for a specific set of waves, tide and sediment parameters (Nielsen, 2009).

Numerous research projects have been done on equilibrium beach profiles dating back to studies done by Keulegan and Krumbein (1949). Bruun (1954) proposed a relationship between water depth and offshore distance:

$$h = x^{2/3}A \tag{2.1}$$

Where,

- h is the average water depth (m)
- x is the offshore distance from shoreline (m)
- A is a site-specific coefficient ($m^{1/3}$)

Dean (1977) confirmed this relationship. Dean (1987) derived an expression to calculate coefficient "A", based on the average sediment fall velocity. The equation to calculate the fall velocity is a simplification of Hallermeier's (1981) equation for fall velocity. The simplification was obtained by assuming beach sediment grains with a diameter range from 0.15 - 0.85 mm and typical temperatures ranging 15 - 25°C (Houston, 1995).

$$A = 0.067w^{0.44} \tag{2.2}$$

$$w = 14{d_{50}}^{1.1} \tag{2.3}$$

Where,

- w is the average sediment fall velocity (cm/s)
- d_{50} is the median grain size (mm)

More research and expansions on this formula exist. This approach is, however, the generally accepted approach to determine equilibrium beach profiles.

2.4 Coastal Sediment Transport

2.4.1 Sediment Transport Mechanisms

Natural sediment transport that occurs at beaches is either wind or water driven. Aeolian sediment transport depends on wind speed and direction at the location of sediment transport. The main water induced sediment transport mechanisms are waves, currents and tides. Sediment in the surf zone is transported as bed load, suspended load and wash load. The total load of sediment that is transported in the surf zone is the sum of the bed load and the suspended load. Table 2-2 defines these transport modes.

Table 2-2: Definition of Sediment Load in the Surf Zone

Sediment Load	Definition
Bed Load	Bed load is sediment that is in contact with the ocean bed for the majority of the time. Sediment particles are transported along the ocean bed through rolling, sliding and jumping (Fredsøe & Deigaard, 1992).
Suspended Load	Suspended load is sediment that is transported through fluid turbulence (Yang, 1996). Therefore, it is not in contact with the ocean bed the majority of the time, but it is deposited on the bed as turbulence decreases.
Wash Load	Wash load is not considered as part of the total load of transported sediment, since it consists of very fine particles that is practically always in suspension (Fredsøe & Deigaard, 1992).

2.4.2 Sediment Transport Directions

Sediment transport in the surf zone is classified as shore parallel or shore normal sediment transport. Sediment transport parallel to the beach occurs due to wave-induced currents, known as longshore currents. Waves that approach the shore at an angle create a current that runs parallel to the shore. Longshore currents move sediment in a direction parallel to the shore in the surf zone. The swash of the water that runs up the beach also hits the shore at an angle due to the direction of the waves. Sediment particles on the beach are moved in the direction of the longshore current through the motion of swash and backwash. The movement of the sediment particles above and below the water level is referred to as longshore drift. This phenomenon is illustrated in Figure 2-2.

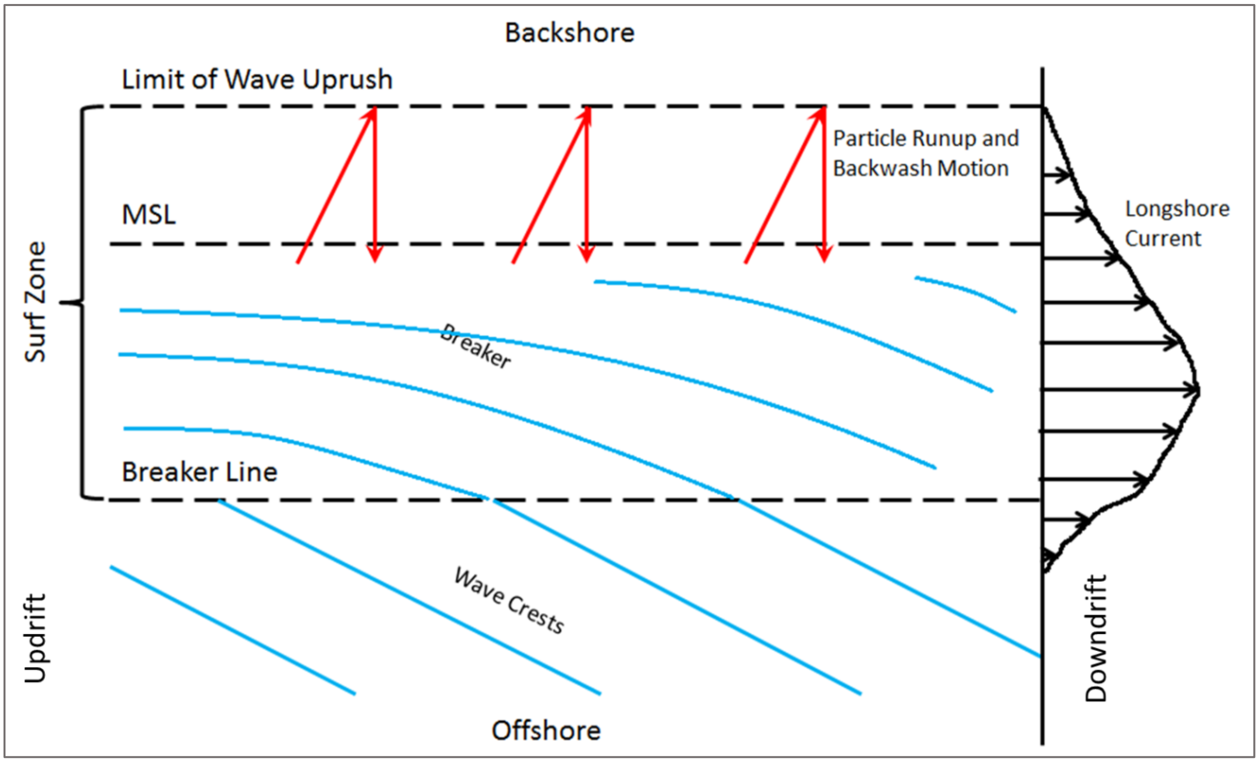


Figure 2-2: Diagram of Longshore Current and Sediment Transport (Schoonees, 2016)

The direction of the longshore sediment transport depends on the wave direction. At a specific site, there usually is a dominant wave direction and thus a dominant direction of longshore sediment transport. If the sediment source is unlimited and the beach is straight, the rate of sediment transport entering and exiting is the same. However, when the sediment source is limited, erosion will occur on the up-drift side of the beach. A constriction on the down-drift side of the beach will on the other hand result in accretion of sediment against the constriction from the up-drift side of the beach.

Cross-shore sediment transport is the term used for shore-normal sediment transport. When waves approach the shore perpendicularly, sediment is transported normal to the shoreline. Cross-shore sediment transport due to water movement occurs from the point where a wave disturbs the seabed (depth of closure) to where the swash zone ends. Cross-shore sediment transport is the main driver for cross-shore beach profile change. Figure 2-3 illustrates two dimensional sediment transport in the coastal zone. Rip currents and longshore currents add a third dimension to coastal sediment transport but are often assumed as nil for the purpose of cross-shore beach profile studies.

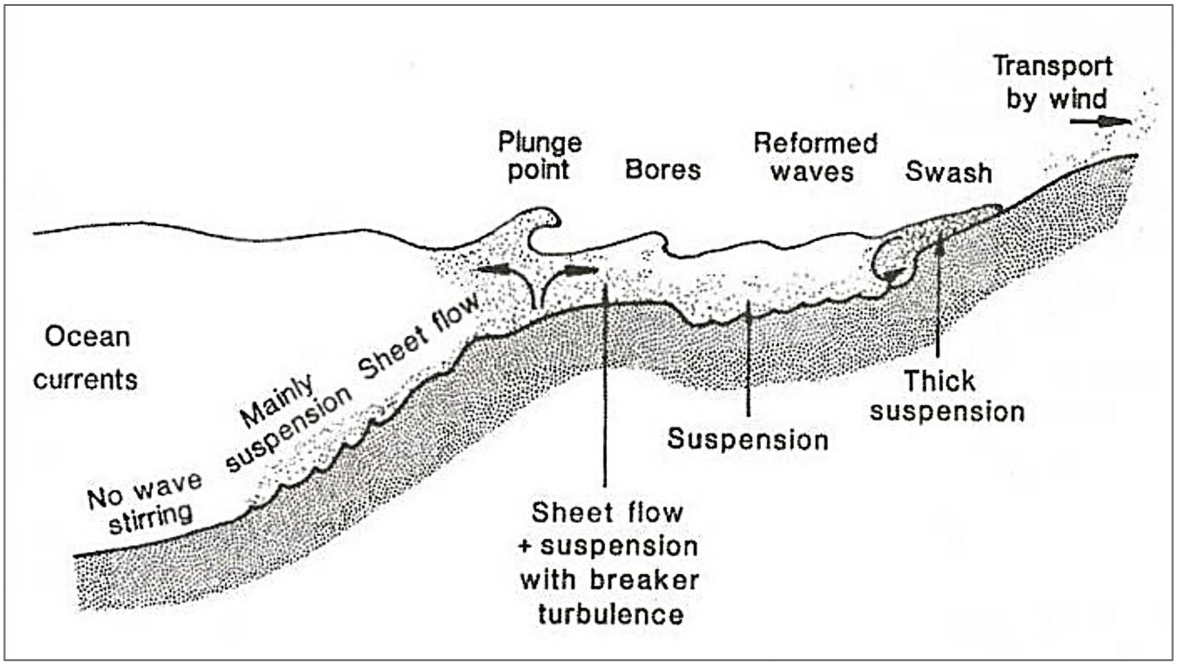


Figure 2-3: Cross-Shore Sediment Transport in the Coastal Zone (Nielsen, 2009)

Dronkers (2005) described important cross-shore sediment transport processes in terms of landward and seaward transport as tabulated in Table 2-3.

Table 2-3: Cross-shore Transport Processes (Dronkers, 2005)

Transport Direction	Transport Process	Explanation
Seaward	Gravity Induced	Gravity causes down-slope sediment transport.
	Undertow	Along the shoreface, net seaward flow occurs in the lower part of the water column. This is known as undertow and is strongest in the breaker zone.
Landward	Streaming	In the absence of bed ripples, a residual forward drift exists in viscous wave boundary layers.
	Wave Asymmetry	Wave orbital velocities are influenced by wave asymmetry. Net sediment transport near the seabed is landward, where sediment transport closer to the surface tends to be seaward. Higher sediment concentration near the seabed results in net landward sediment transport.

2.5 SEDIMENT PROPERTIES

2.5.1 Particle Size and Shape

The most basic properties of a sediment particle are its shape and size. Allen (1968) defined particle shapes varying from spherical to acicular (Table 2-4). Particle shapes can be expressed in terms of the shape factor (S_P) as defined by Corey (1949) (Schultz *et al*., 1954):

$$S_P = \frac{c}{\sqrt{ab}} \tag{2.4}$$

Where,

- S_P is the shape factor (-)
- a is the length of the longest mutually perpendicular axis through the particle (μm)
- b is the length of the intermediate mutually perpendicular axis through the particle (μm)
- c is the length of the shortest mutually perpendicular axis through the particle (μm)

Table 2-4: Definition of Sediment Particle Shapes (Allen, 1968)

Shape	**Definition**
Acicular	Needle-shaped
Angular	Sharp-edged or having roughly polyhedral shape
Crystalline	Freely developed in a fluid medium of geometric shape
Dendritic	Having a branched crystalline shape
Fibrous	Regularly or irregularly thread-like
Flaky	Plate-like
Granular	Having approximately an equidimensional irregular shape
Irregular	Lacking any symmetry
Modular	Having rounded, irregular shape
Spherical	Global shape

The most convenient property of sediment to measure is its size. In order to determine the particle size distribution of a sediment sample, a sieve analysis is typically done. The results from the sieve analysis are presented in a frequency curve from which the sieve diameters (d_s) can be read off. The d_{50} diameter represents the median diameter of the sediment sample. Table 2-5 lists grain size ranges of sediments between clay (< 0.002mm) and gravel (> 2mm).

Table 2-5: Size Ranges of Sediment Particles finer than Gravel (Knappet & Craig, 2012)

Sediment Type	Size Range (mm)
Silt	0.002-0.049
Very Fine Sand	0.050-0.099
Fine Sand	0.100-0.249
Medium Sand	0.250-0.499
Coarse Sand	0.500-0.999
Very Coarse Sand	1.000-1.999

Sediment particles in a sediment sample do not consist of just one diameter. The variation of the diameters of the sediment particle is referred to as the gradation of the sediment sample. Sediment gradation is quantified as the ratio between two diameter fractiles of the sediment sample (Nielsen, 2009), for example, d_{90}/d_{10}.

A gradation of close to 1.0 is indicative of well sorted sediments and a large ratio indicates well graded sediments. When a sediment sample is well graded, it means that in each sieve size range there are more or less the same amount of sediment particles and that none of the intermediate sizes are lacking (Knappet & Craig, 2012). A well-sorted sediment sample is a sample where the diameter of most of the sediment particles fall within a small interval.

2.5.2 Specific Gravity

The density of a sediment particle depends on its mineral composition. In practice, specific gravity (or relative density) is used as an indicator of the density of sediment. Specific gravity of a sediment particle is the relationship between the density of the particle and the density of water at 4°C (Chadwick *et al*., 2004). Natural sediment particles that are found in water usually have quartz or carbonate as a primary mineral and have a specific gravity of approximately 2.65 (Yang, 1996).

2.5.3 Settling Velocity

Settling velocity, also referred to as fall velocity, is the terminal velocity of a sediment particle in fluid due to gravity. The settling velocity depends on the following parameters of the sediment particle:

- Grain size and shape
- Specific gravity
- Dynamic viscosity of the fluid

A suspended particle in a fluid volume will experience a downward gravitational force (F_G) and an upward buoyancy force (F_B). In order for the vertical forces to be in equilibrium, the gravitational and buoyancy forces are balanced by drag force (F_D):

$$F_G = g \cdot \rho_s \cdot V \tag{2.5}$$

$$F_B = g \cdot \rho_w \cdot V \tag{2.6}$$

$$F_D = \frac{1}{2} \cdot C_D \cdot \rho \cdot \mathrm{v}^{2} \cdot A \tag{2.7}$$

Where,

- F_G, F_B, F_D is gravitational, buoyancy and drag force (N)
- g is gravitational acceleration (m/s^2)
- ρ_s, ρ_w is sediment and water density (kg/m^3)
- V is volume (m^3)
- C_D is drag coefficient (-)
- v is velocity (m/s)
- A is area of particle perpendicular to direction of movement (m^2)

The settling velocity is derived as:

$$w_s = \sqrt{\frac{4(\frac{\rho_s}{\rho_w} - 1) \cdot g \cdot d}{3C_D}} \tag{2.8}$$

Where,

- w_s is settling velocity of single particle (m/s)
- d is sediment grain diameter (m)

Richardson & Zaki (1997) observed that the settling velocity of a particle decreases with an increase in the amount of settling particles. The ratio of the decreased velocity over the velocity of a single particle is:

$$\frac{w_{sm}}{w_s} = (1 - C)^n \tag{2.9}$$

Where,

- w_{sm} is settling velocity of a particle amongst other settling particles (m/s)
- C is volume concentration
- n =
  - $4.35R^{-0.03}$, $0.2 < R < 1$
  - $4.45R^{-0.10}$, $1 < R < 500$
  - 2.39, $500 < R$

The Reynolds number, R, of a particle is:

$$Re = \frac{w_s d}{v} \tag{2.10}$$

Where,

- Re is the Reynolds number
- w_s is settling velocity of single particle (m/s)
- v is kinematic viscosity (m^2/s)
- d is the sediment grain diameter (m)

2.6 Beach and Surf Zone - Cross-Shore Profile Dynamics

2.6.1 Surf zone processes and impact on cross-shore sediment transport

Sediment transport on the beach and in the surf zone is caused by the impact of wind and water motion on the beach face. The amount of sediment that is transported on the beach face differs as the amount of energy that has to be dissipated in the surf zone changes. The main water processes that exert forces on the beach face are waves, tides and currents. Numerous studies have been done in order to attempt to quantify the effect of surf zone processes on cross-shore beach profiles. The focus of this section is to define the processes (applicable to this study) influencing cross-shore sediment transport and to summarise the findings of previous studies.

2.6.2 Sea Level Variation

2.6.2.1 Definition

Sea level variation is a common occurrence at the shore. On a daily basis tides influence the sea level. Winds, currents and storms also contribute to sea level variation through wind set-up, wave set-up and storm surge (Chadwick *et al.,* 2004). Long waves in semi-enclosed water bodies (estuaries and harbours) may cause seiches - standing waves. Over longer periods (decades or more) sea level rise and fall occur due to climatic cycles and isostatic uplift. Although all of the above-mentioned causes for sea level variation may be regarded as long waves, this study will regard them as water level variation.

Tides

Ordinary tide waves are caused by the relative position of the sun and the moon to the Earth. The sun and moon both exert gravity forces on Earth, with the moon exerting larger forces than the sun because of its shorter distance from the Earth. These forces pull water away from the surface of the Earth resulting in raised water levels at certain locations on Earth and lowered water levels at other places on Earth. The gravitational pull of the sun and moon along with the centripetal force of the spinning Earth (Trujillo & Thurman, 2007) creates two tidal bulges, as shown in Figure 2-4.

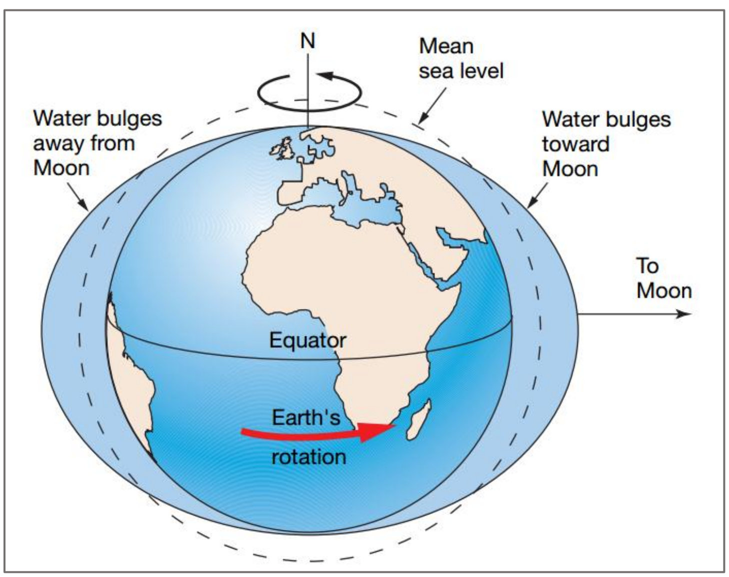


Figure 2-4: Tidal bulges caused by the moon and Earth's rotation (Trujillo & Thurman, 2007)

As the tidal bulge reaches the shoreline, it causes a periodic increase in the water level. After the tidal bulge has passed, the water level returns to mean sea level and then gets lower before it starts increasing again due to a tidal bulge. The rise and fall of water levels at the shore are referred to as high and low tide.

Tides are seen as waves that are created due to tidal forces (Warren & Wunsch, 2007). These waves either have a diurnal or semi-diurnal cycle, meaning they either have a 24 hour wave length or 12 hour wave length. The difference between the semi-diurnal lunar component and the semi-diurnal solar component causes the spring-neap tide cycle (Dronkers, 2005). Spring tide is the highest high tide reached in a lunar cycle and neap tide is when the difference between high and low tide are at its lowest in a lunar cycle. Figure 2-5 illustrates the spring-neap tidal cycle.

The moon’s declination towards the Equator changes from highest declination to the North to highest declination to the South and back during one lunar cycle. This phenomenon is referred to as the diurnal inequality. The diurnal inequality explains why a location experiences either a diurnal, semi-diurnal or mixed tide. Figure 2-6 shows the tidal pattern and wavelengths for the different tidal regimes.

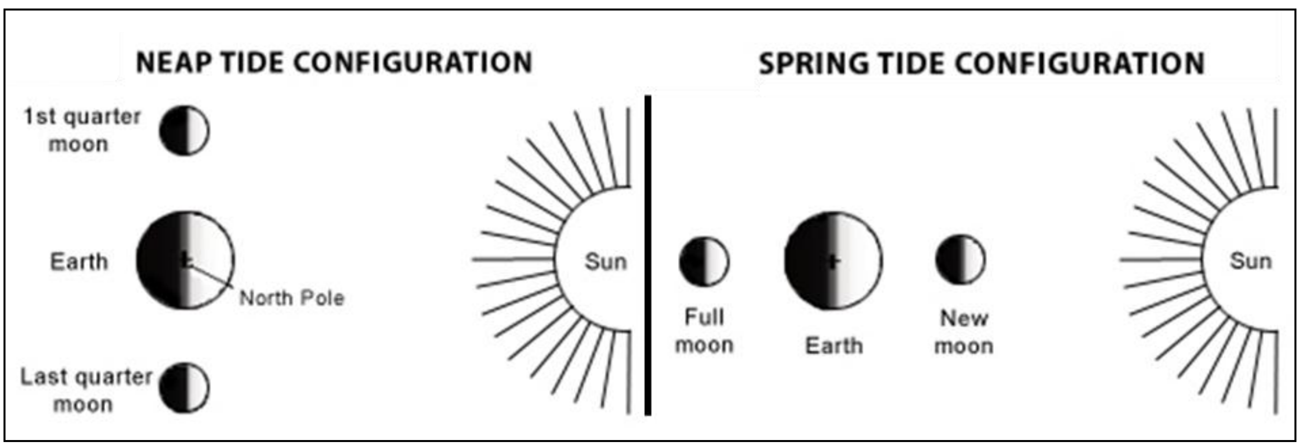


Figure 2-5: Spring-Neap Tide Configuration (Woods Hole Oceanographic Institution, 2016)

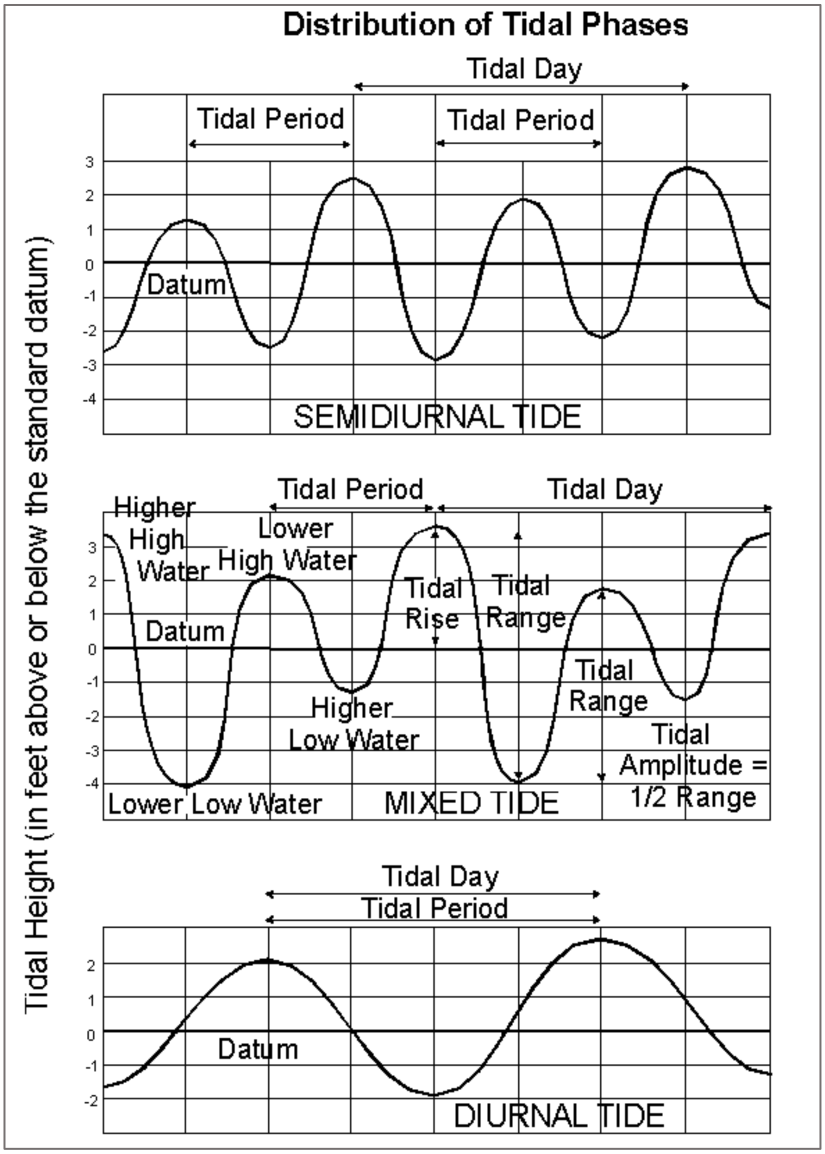


Figure 2-6: Semi-Diurnal, Mixed and Diurnal Tides caused by the Diurnal Inequality (NOAA, 2016)

Pressure Driven Storm Surge

Wind fields over the ocean causes low- and high-pressure systems. The water level beneath a low-pressure system will rise due to the lower pressure exerted on the water surface. On the other hand, the water level will lower when exposed to higher pressures due to a high-pressure system.

Low-pressure systems are formed when warm and cold bodies of air meet. When warm and cold air meets, the warm air moves upward, since it is less dense than the cold air. This sudden movement of air particles results in a low-pressure area. More cold air will blow toward the system as it moves from a higher to a lower pressure, causing more warm air to be driven upward. This process continues until the pressure difference is equalized after a few days to a week. In high-pressure systems, the reverse occurs and wind is blown outward from the pressure system, causing a downward pressure. Figure 2-7 illustrates the upward or downward movement of air in low- and high-pressure systems.

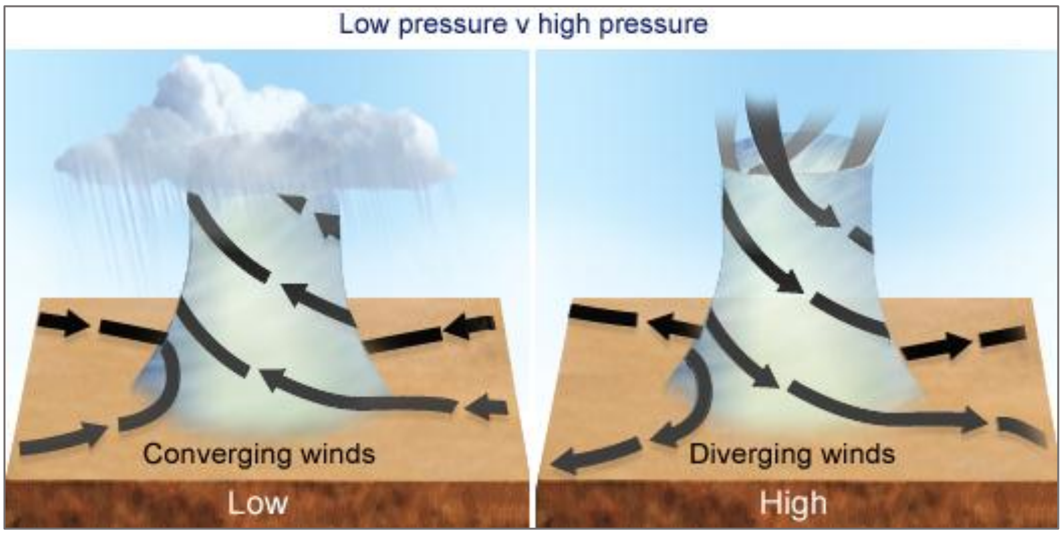


Figure 2-7: Low- and High-Pressure Systems (Siems, 2013)

Low- and high-pressure systems rotate because of the rotation of the Earth and the Coriolis effect (UCAR, 2016). In the North, low-pressure systems rotate counterclockwise and in the South the systems rotate clockwise (Landberg, 2015). The opposite is true for high-pressure systems.

When a low-pressure system is stationary, it only causes a local sea level rise of 1cm for each hPa of low pressure (Finkl, 2012). When a low-pressure system moves, it may cause a sea level rise of up to three times as much as a stationary system.

Storms go hand in hand with low-pressure systems, since the warm air that is forced upward contains lots of moisture. The water condensates as it cools down and clouds are formed, which leads to rain. Strong winds also occur due to the rush of cold air. The rise of water level, due to low-pressure systems, occurs during storms and is therefore, referred to as pressure driven storm surge.

Wind Set-up

Wind set-up is often regarded as a form of storm surge: wind driven storm surge. During a storm, wind set-up is the largest factor contributing to storm surge. It can, however, occur in the absence of a storm.

Wind set-up is caused when strong winds blow towards the coast, creating stresses on the water surface (Harrison, 1967). These stresses enable the wind to push the water towards the shore, creating wind set-up at the shoreline line. Figure 2-8 illustrates the movement of wind set-up (wind driven surge) and storm surge (pressure driven surge) towards the shore during a storm.

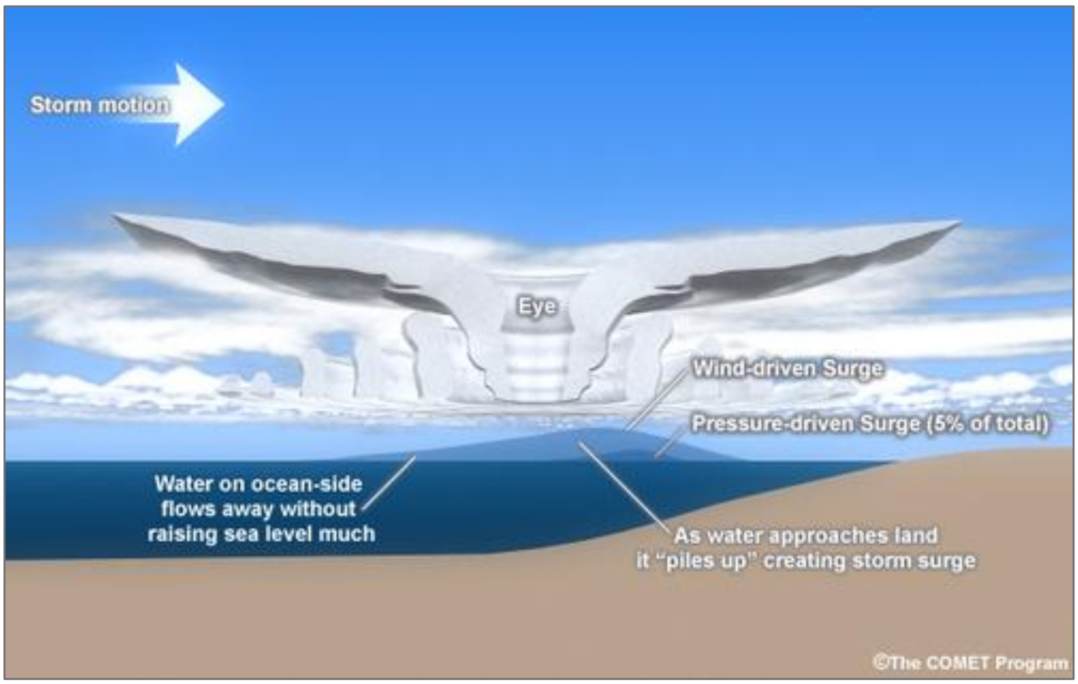


Figure 2-8: Pressure Storm Surge and Wind Set-up during a Storm (National Hurricane Center, 2016)

Strong winds may also blow water away from the coast, resulting in the lowering of the water level at the shore. It is easiest to describe this effect using a lake as an example. When strong winds blow in a prevailing direction, water in a lake is set-up toward the side to which the wind is blowing. The opposite side of the lake experiences a lowering in the water level as indicated in Figure 2-9.

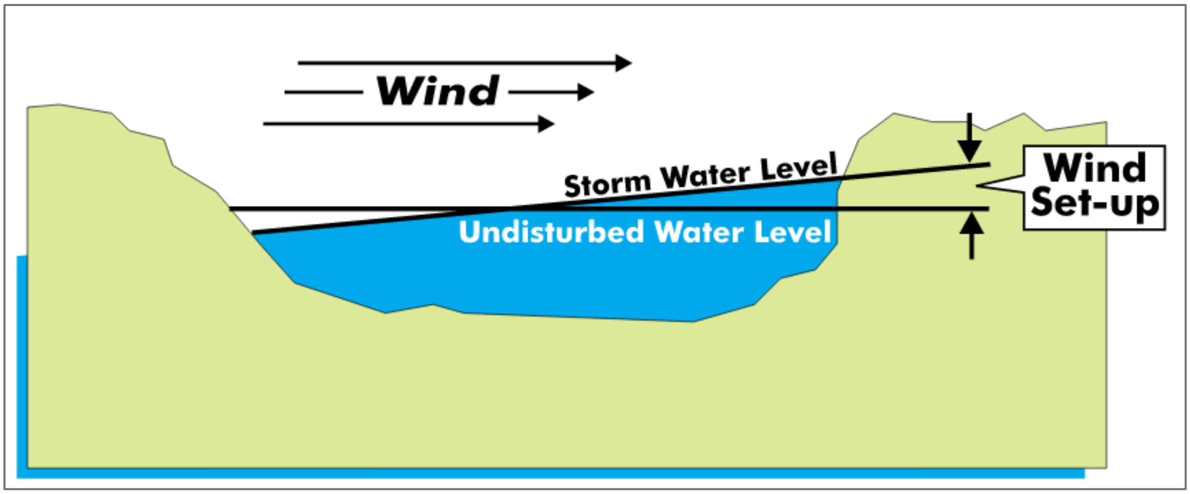


Figure 2-9: Wind set-up and set-down in a lake (Manninen & Gauthier, 1999)

Wave Set-up and Run-up

Wave set-up and set-down are caused through momentum transfer (Stive & Wind, 1982). Waves are induced through the transfer of momentum of offshore winds to the water surface. The waves approach the shore and as they reach shallow depths the energy of the waves are dissipated through the process of shoaling. When the waves enter the surf zone, the wave energy is also dissipated through the breaking of the waves.

Although the wave energy is dissipated in the surf zone, the momentum of waves is transferred to the water column, resulting in a tilt of the sea surface (FEMA, 2002). The tilt in the sea level causes wave set-up shoreward of the breaker line and wave set-down just seaward of the surf zone. This phenomenon is illustrated in Figure 2-10.

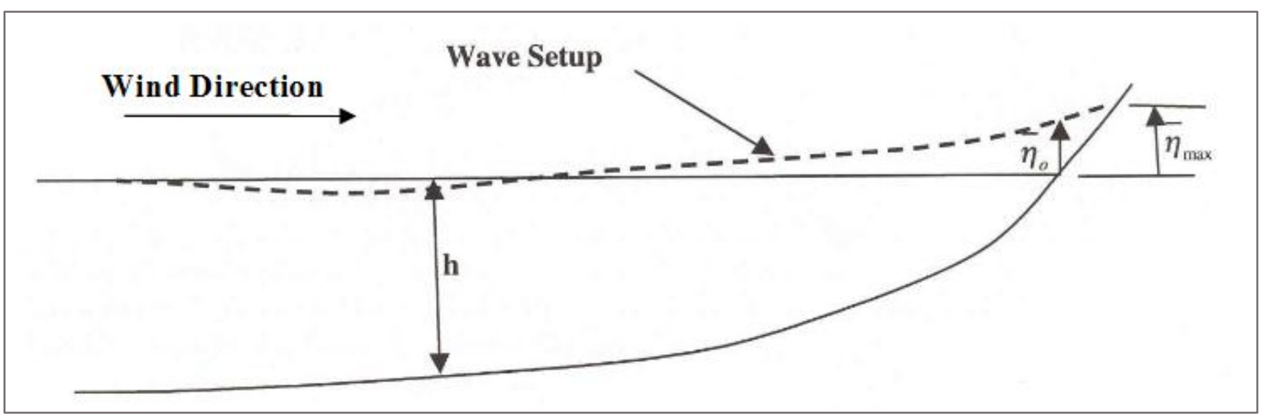


Figure 2-10: Wave set-up and set-down (FEMA, 2002)

Wave run-up (Figure 2-11) is not a form of sea level rise, but it does cause the water to move up the beach face beyond the static water level elevation resulting from tides, surge and wave set-up. The amount of wave run-up that occurs is site-depended. The wave characteristics, static water level and beach face characteristics all play a significant role (FEMA, 2005). Waves containing less energy will cause less wave run-up, since less energy has to be dissipated. In an environment where the wave and sediment properties remain constant, a steeper beach slope will result in less wave run-up, since gravitational pull is larger. Coarse beach sediment will dissipate the wave energy faster than fine beach sediment, resulting in less wave run-up. The porosity of the beach face also influences the amount of wave run-up. If a beach face is more porous, ground water flow will increase and wave run-up will decrease.

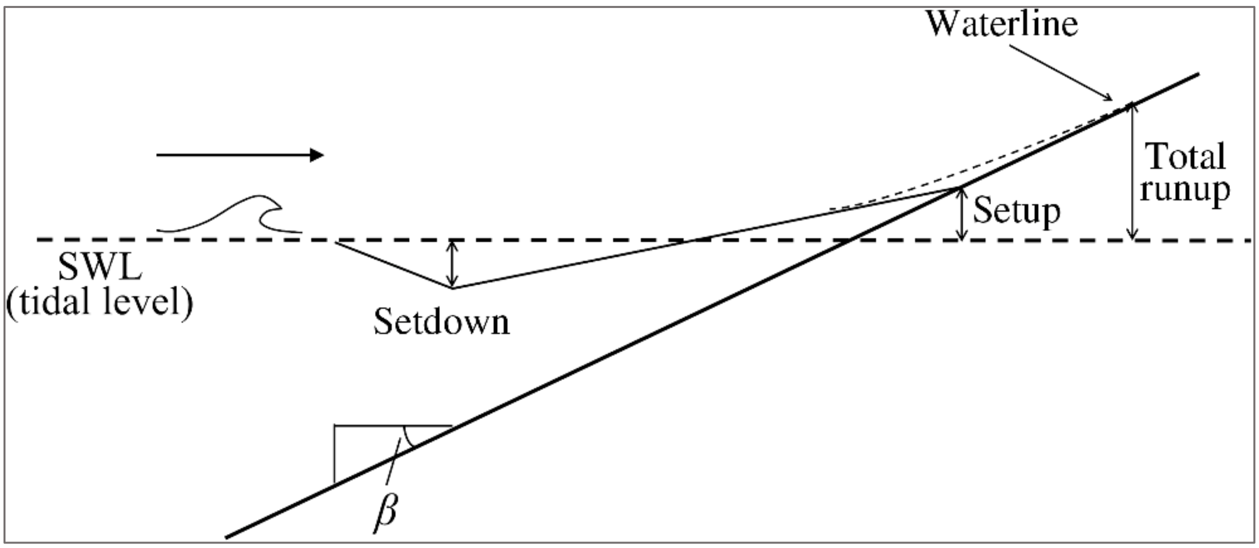


Figure 2-11: Wave Run-up (Chang *et al.*, 2015)

Climatic and Isostatic Uplift Sea Level Rise

Thermal expansion of water bodies and the melting of land-based ice cause climatic sea level rise. Thermal expansion of a water body happens when the temperature of the water body increases, causing an increase in the kinetic energy of the water particles (Schellnhuber, 2006). The increase in the kinetic energy results in larger spaces between water particles and thus causes an expansion in the volume of the water body. The melting of land-based ice causes a net increase in the volume of water in the ocean. Due to rising global temperatures, glaciers are currently melting at higher rates than in the past.

Since the sea level stabilized after the previous ice age, the sea level has remained relatively constant until late in the 19th century. Proper data does not exist to estimate the average sea level rise, since the late 19th century; however, satellite images taken since 1990 revealed an average sea level rise of 2.8 to 3.6mm per year since 1993 (IPCC, 2014). Figure 2-12 indicates sea level rise figures predicted for the future based on historically recorded data from 1986 to 2005. It is predicted that future sea level rise will mainly be caused by thermal expansion.

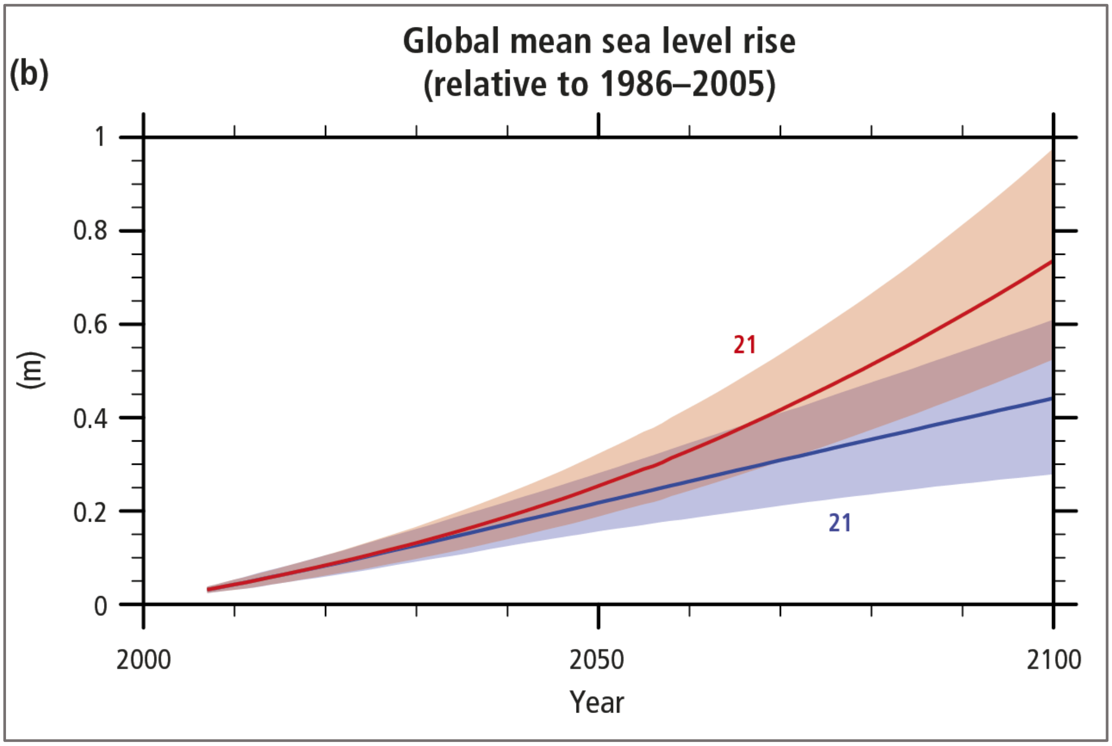


Figure 2-12: Future Sea Level Rise (IPCC, 2014)

Although it is clear that the global sea level is rising, there are still places where the sea level changes at a lower rate, remains unchanged or even lowers relative to the land. The probable cause for this is the isostatic uplift of the Earth's crust (Chadwick *et al*., 2004). Areas on land that have been covered by ice sheets or glaciers were exposed to large masses pressing the landmass downward. Due to climate change, the ice sheets and glaciers started to melt, resulting in less pressure exercised onto the landmasses. The rebound of the landmass to an equilibrium position after the pressure has been removed, is referred to as isostatic uplift (Davidson-Arnott, 2010). As the land mass is lifted due to isostatic, the local sea level lowers relative to the land. Figure 2-13 illustrates the concept of isostatic uplift.

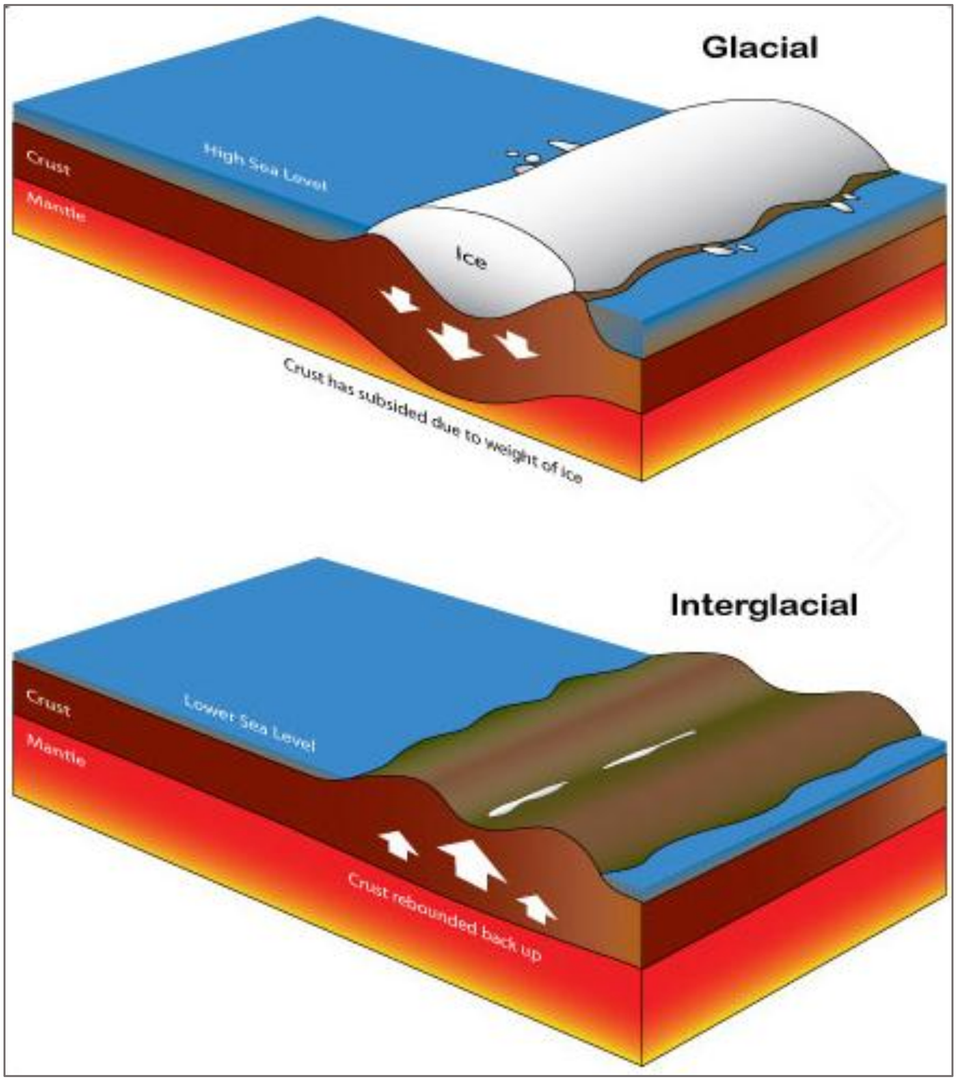


Figure 2-13: Isostatic uplift (NERC British Geological Survey, 2016)

2.6.2.2 Impact on cross-shore sediment transport

Sea level rise over the long term is caused due to climatic changes. A study done by Bruun (1962) concluded that beach profiles will change due to rising sea levels. Since shorelines move landward when the sea level rises, waves also impact areas landward of the original breaker zone. This induces erosion of upper beaches (dunes). The eroded sediment is transported and deposited immediately offshore from the breaker zone. The deposition of the sediment offshore results in a rise in the nearshore seabed. According to Bruun (1962) this rise is equal to the rise in sea level. The rate at which the shoreline retreats due to sea level rise can be estimated using a simplified equation for Bruun's estimated shoreline retreat rate.

$$R = \frac{S \cdot y}{h + B} \tag{2.11}$$

Where,

- R is the shoreline retreat rate (m)
- S is the rise in sea level (m)
- y is the width of the cross-shore profile (m)
- h is the closure depth (m)
- B is the elevation of the beach or dune height (m)

Leatherman *et al*. (2000) did a study to find a relation between sea level rise and beach erosion for some beaches in the United States of America. Leatherman *et al*. (2000) concluded (similarly to Bruun, 1962) that due to a rise in the sea level, high energy waves can reach higher up the beach. This causes erosion of the upper beach and accretion just offshore from the breaker zone. Based on measurements taken at numerous beaches, a correlation (r^2) of 0.89 was found between sea level rise and coastal erosion.

When looking at shorter term sea level variation and its impact on coastal erosion and accretion, numerous literature can be found on tidal sea level variation. Hattori (2011) studied sediment transport at Oarai Beach, Japan. From his observations, he found that net sediment transport was directed onshore during ebb tide and offshore during flood. According to Hattori (2011) there is thus a negative correlation between sediment transport and the direction of tidal flow. It was also concluded that the net sediment transport direction was significantly governed by the tide.

A more recent study done by Jensen *et al*. (2009) analysed the effect of tides on sediment transport at beaches in Denmark. This study found that sand bars migrated onshore during water level increases, eventually leading to a heightened berm. No net transport rates were observed, possibly due to rip currents breaking through the offshore bars and transporting sediment offshore.

Shi *et al*. (2013) concluded that the effect of tide-only sediment transport is negligible. Tides do, however, cause a shift in wave-induced erosion areas, resulting in different erosion patterns as tides change. Although all of the above-mentioned studies on tidal effect on sediment transport are also based on this concept, it was never explicitly mentioned.

Vellinga (1982) studied storm surge and its effect on beach profile change. Storm surges cause significant damage to dunes located in the upper beach. Figure 2-14 illustrates the change in beach profile due to storm surge.

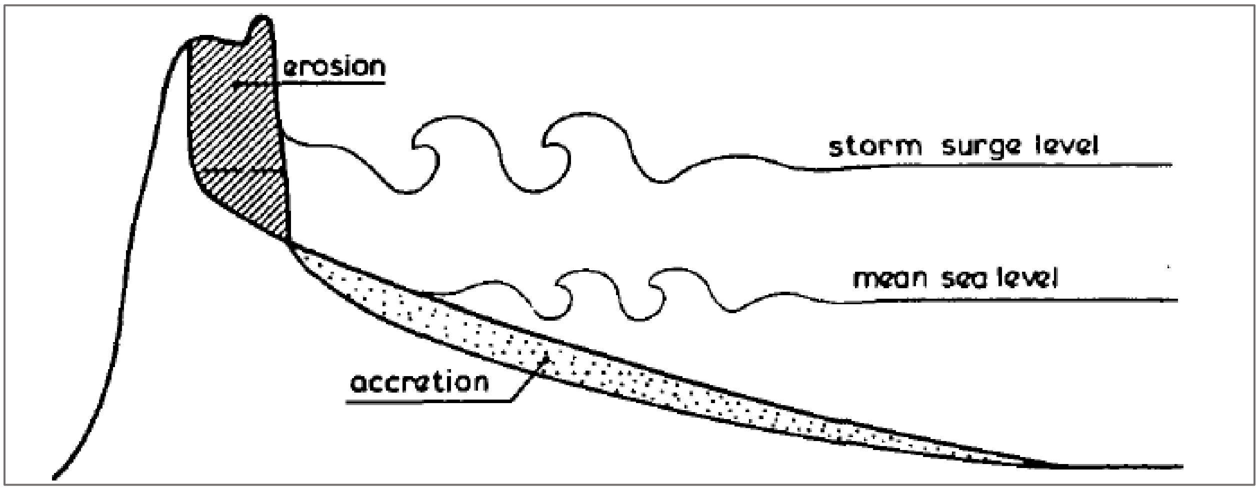


Figure 2-14: Beach Erosion and Accretion due to Storm Surge (Vellinga, 1982)

The reason for the change as illustrated above is similar to the reason for coastal erosion and accretion due to tides. As the sea level rise, the shoreline moves landward, causing waves to break on much steeper beach profiles. Steep beach profiles are less stable and erode rapidly as energy is exerted onto it (Vellinga, 1982). As the upper beach erodes, the beach gradient decreases and less sediment is eroded until the process reaches equilibrium and a new beach profile is formed. The eroded sediment from the upper beach is deposited offshore, resulting in a raised offshore beach profile.

2.6.3 Storm Duration

2.6.3.1 Definition

Storm duration is simply the amount of time that passes from the beginning to the end of a storm. The severity of a storm depends on the return period of a storm: A storm with a 100-year return period is much more severe than a storm with a 50-year return period. When engineers design structures near the coast, the design is based on a storm with a specific return period. Therefore, if an engineer designs for temporary works, the design return period of a storm will be 5 to 10 years or even shorter. If the engineer has to design a structure that is meant to last a lifetime, storm return periods of a 100 years or greater may be used. Such a design is usually over-designed and will have a much higher cost than designs for shorter return periods.

Storms, however, do not just occur once a year or once in ten years. A number of storms may hit a location within a year. It is difficult to specify exactly what classifies as a storm and therefore the Peak over Threshold (PoT) has been introduced. Through this method threshold values are defined for significant wave height, storm duration and time between storms.

Wave conditions with wave heights higher than the threshold wave height, duration longer than the threshold duration and proximity of more than the threshold time before or after the previous storms, constitutes as a storm. There is no clear method on the selection of the threshold significant wave height. A study done by Lopatoukhin *et al*. (2004) used threshold values of 2 and 3 times the annual mean wave height for the Baltic, Barents, Black and Caspian Seas. Masselink *et al*. (2016) identified coastal storm conditions on a 5% significant wave height exceedance for storms on the South West coast of England. It was suggested that a predetermined number of events with a specific duration can be isolated per year. From the isolated events, a threshold significant wave height can be determined (Bernadara, 2012).

Bernadara (2012) suggested minimum storm durations of 6 hours, with at least 24 hours in between two consecutive storms. If the significant wave heights drop to below the threshold value for less than 12 hours, it may still be regarded as part of the storm. Once storm events are classified, the storm parameters may be read from the data.

2.6.3.2 Impact on cross-shore sediment transport

Hydrodynamic factors that influence the severity of beach profile change during storms include peak wave period, maximum wave height, water levels and wave direction. There is, however, little literature on how storms with the same peak and significant wave conditions, but different durations, affect the cross-shore beach profile evolution.

Enough literature was, however, found to explain how the duration of impact of constant wave conditions influences beach profile response. The principle on which most of the studies were based, was that an equilibrium beach profile may theoretically be reached when the beach face is exposed to the same wave conditions over a long enough time period. The equilibrium beach profile theory is discussed in Section 2.3 and therefore the focus of this section was to provide literature on whether and how equilibrium beach profiles develop in practice.

Kraus & Larson (1988) documented large wave tank experimental data that indicated that cross-shore beach profile evolution occurs rapidly under storm wave conditions, but that over time, the amount of cross-shore sediment transport decreases. The aim of the experimental runs was to document intermediate cross-shore beach profiles until equilibrium states were reached, but even though cross-shore sediment transport significantly decreased as the duration of impact increased, the beach profiles still exhibited signs of evolution by the time the final beach profiles were surveyed. The data concluded that longer storm durations caused more cross-shore sediment transport, but that the average rate of beach profile change over the entire storm period is larger for shorter storm durations than for longer storm durations. The same rapid transformation of cross-shore beach profiles was observed within the first few hours of storm wave impact in experimental studies done by Kemp (1960). As the impact duration increased, the significance of cross-shore beach profile change, decreased.

Dalrymple & Thompson (1976) also did experimental studies on equilibrium beach profiles. Although the focus was to determine how experimental scaling influences experimental outcomes, the two prototype experimental runs did reach equilibrium profiles under both larger and smaller wave conditions.

2.6.4 Long Waves

2.6.4.1 Definition

Waves in the surf zone are formed through a disturbance of the water surface due to wind or disturbance of the water bottom due to tectonic shifts. Waves generated by wind are divided into sea or swell waves, based on the origin of the wind. Waves generated by local wind are named wind waves. Swell waves are waves that have been generated by winds offshore and propagate towards shore.

The direction, fetch and speed of the wind along with bathymetrical influences cause a difference in the properties of the wave that approach the shore. Table 2-6 lists the main wave parameters along with equations to calculate the wave parameters based on Airy (linear) Wave Theory (Chadwick *et al.*, 2004).

Ocean waves are often classified in terms of their wave period. Munk (1950) identified the forces that cause waves with different periods. Figure 2-15 is a redrawn version of Munk's (1950) wave classification system based on wave period.

Waves with wave periods of more than 30 seconds are known as long waves. Therefore, a long wave is any infra-gravity, long period, ordinary tidal or trans-tidal wave. For the purpose of this study, long waves will include infra-gravity and long period waves, induced by earthquakes. Long period waves induced by storms, tidal and transtidal waves, will be handled as short term rise in sea level.

Table 2-6: Wave Parameters and Equations to Calculate Wave Parameters

Wave Parameter	Definition	Equation
Wave Height (H)	Height of the wave measured from trough to crest in meters	Not Applicable
Wavelength (L)	Distance between adjacent crests measured in meters	$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi H}{L}$
Period (T)	Time it takes in seconds for one complete wave (two consecutive crests or troughs) to pass a given point	$T = 1/f$
Frequency (f)	Number of complete waves that pass a point per second, measured in Hertz (Hz)	$f = 1/T$
Wave Celerity (C)	Horizontal speed of a propagating wave measured in m/s	$C = \sqrt{\frac{gL}{2\pi}\tanh\frac{2\pi H}{L}}$
Wave Direction (°)	Direction in which wave propagates indicated in degrees	Not Applicable

***g is the gravitational acceleration (m/s^2)**

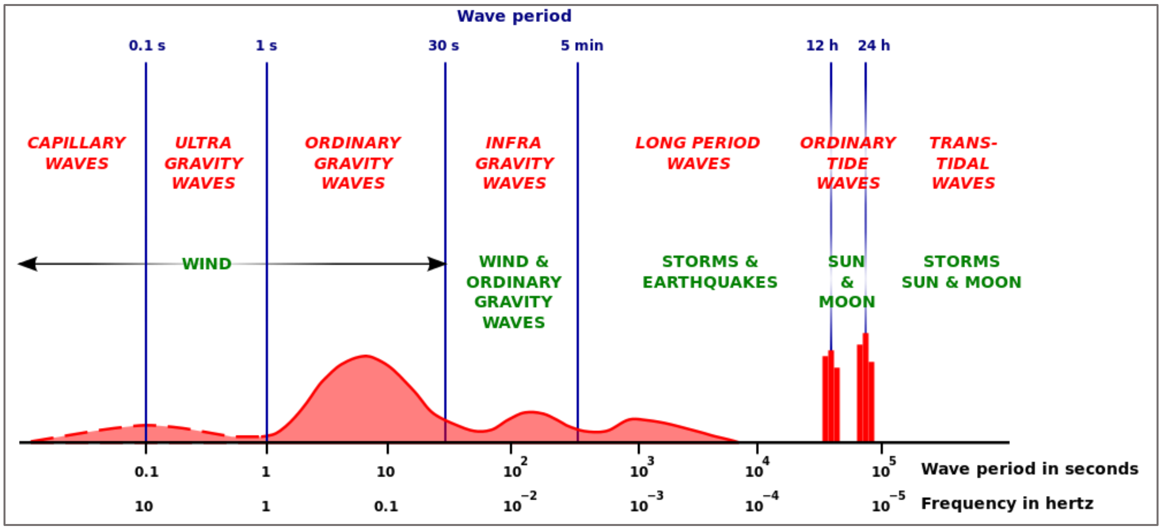


Figure 2-15: Wave period spectrum and driving forces (Wikipedia, 2016)

Infra-gravity Waves

Infra-gravity waves typically have a period of 25 to 200 seconds (Okihiro *et al.*, 1992). The Coastal Engineering Manual (CEM, 2003) describes three categories of infra-gravity waves:

- Bound Long Waves: Wave groups are sets of waves where the sequential wave heights grow until a peak and then fall. Wave groups that approach the shore develop gradients in radiation stress (CEM, 2003). This causes a slight rise in sea water level, when waves with smaller wave heights, pass a point and a slight fall in sea water level, when waves with larger wave heights pass through. The rise and fall of the water due to the passing of wave groups form a long wave (also referred to as surf beat). Figure 2-16 illustrates the passing of wave groups and the generated surf beat that accompanies wave groups.
- Edge Waves: Edge waves are bound long waves, that are reflected from the shoreline. Through the reflection of the long wave, the wave is enabled to propagate freely, since it is not bound to the celerity of the wave group anymore. Edge waves are, however, long waves that are trapped within the surf zone due to refraction and travels alongshore with an antinode at the shoreline (CEM, 2003).
- Leaky Waves: Leaky waves are similar to edge waves in the sense that they are freely propagating waves. They are, however, not restricted by the surf zone bathymetry and reflect out to the deep sea.

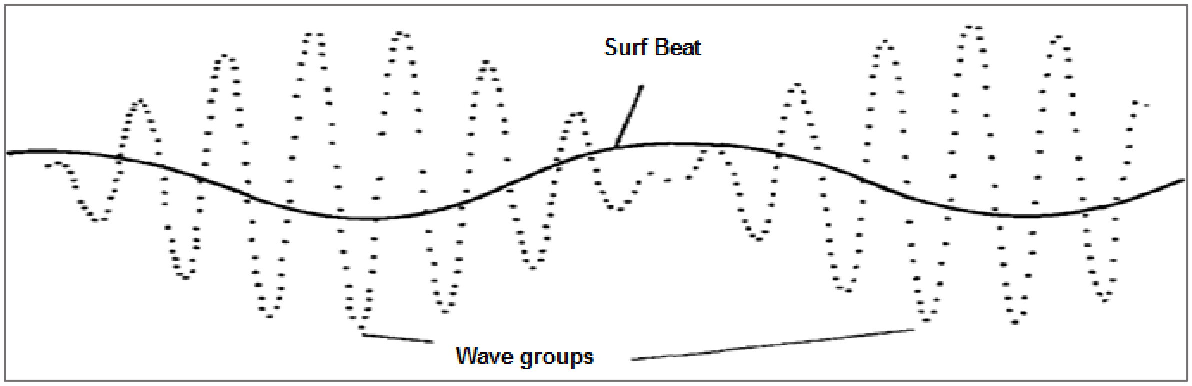


Figure 2-16: Wave groups and the resulting surf beat (Denny, 1988)

When all waves approaching the shore have nearly the same wave number ($\frac{2\pi}{L}$), the waves are monochromatic. Bichromatic waves are waves where the wave is concentrated in almost two wave numbers (Nohara, 2007). Wave groups with a regular surf beat are formed through the process of superposition of bichromatic waves. The superposition of wave trains with more than two wave numbers also induce surf beat. This surf beat is, however, irregular (Van Dorn, 1974).

Longer Period Waves

One of the causes of waves with longer periods than infra-gravity waves, is seismic activity. The other cause seems to be related to storms, but will be discussed as a temporary rise in sea level. Seismic activities that can result in a tsunami, are mainly one of the following:

- A slip between tectonic plates
- Sudden erosion of a large amount of sediment on the ocean bottom
- Volcanic activity on the ocean floor
- Although not seismic: Impact of a meteor falling into the ocean

Figure 2-17 illustrates how each of the above-mentioned activities causes a tsunami. The wavelength of a tsunami depends on the cause and magnitude of the impact. A tsunami can have a wavelength between 5 minutes to 90 minutes (International Tsunami Information Center, 2016). Tsunamis travel up to 800km/h with wave heights that are barely noticeable in the deep sea. As soon as the wave starts touching the ocean floor the speed of the tsunami starts reducing. The build-up of energy, however, causes the wave height of the tsunami to grow during the shoaling process until it reaches a wave height of several meters (Nelson, 2016).

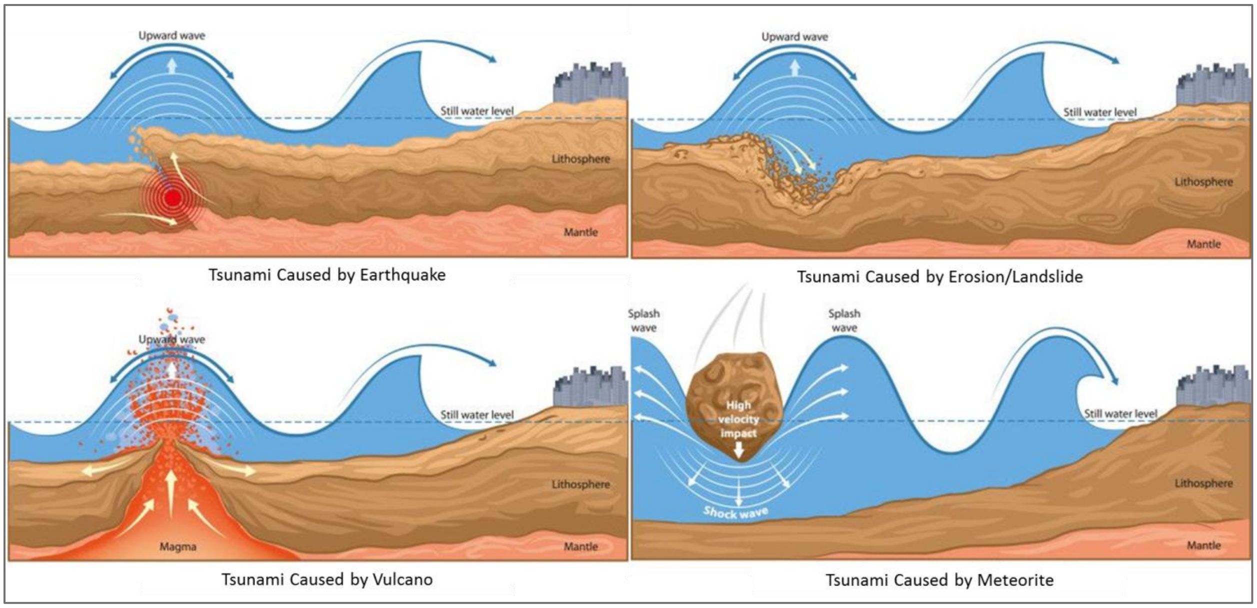


Figure 2-17: Formation of Tsunami Waves (Lockwood, 2016)

2.6.4.2 Impact on cross-shore sediment transport

Numerous studies have been done on how infra-gravity waves influence cross-shore beach profile evolution. Most of these studies focused on the position of the longshore sand bar due to the standing wave patterns caused by long waves. Short (1975) concluded that bar spacing is related to reflecting free long waves. Contradicting results were, however, obtained by Dally (1987), suggesting that there is little experimental evidence, that supports the theory, that long waves have a significant impact on bar formation.

In 1989, Roelvink and Stive stated that long waves create smoother sand bars with reduced bar heights. Long waves also move these bars in an offshore direction. In general this process causes less erosion in the inner surf zone. Roelvink (1993) then suggested that narrow-banded surf beats have a great influence on bar formation.

Some later studies focused more on the quantification of cross-shore sediment transport due to the impact of infra-gravity waves. Baldock *et al.* (2010) did a comprehensive experimental study in scaled wave tanks. Two control experiments were conducted to determine the cross-shore beach profile response to erosive and accretive monochromatic short waves.

Additional experiments were conducted with the same monochromatic wave conditions, but with added free long waves in order to determine what effect the free long waves have on the cross-shore beach profile evolution. Bichromatic short waves, with the same wave energy as the monochromatic short waves, were modelled in the flume to analyse the effect of bound wave groups caused by bichromatic waves on cross-shore beach profile response.

The analysis of the effect of bound and free long waves on cross-shore sediment transport, was done based on the difference between the control cases and the experiments including bound and free long waves. Table 2-7 summarises the observed effects of the free and bound long waves on the cross-shore sediment transport regime.

Table 2-7: Effects of long waves on cross-shore sediment transport (Baldock, 2010)

Long Wave Type	**Monochromatic Sediment Transport**	**Effect of Long Wave**
Free	Accretive Conditions	Increased onshore sediment transport
	Erosive Conditions	Decreased offshore sediment transport
Bound	Accretive Conditions	Decreased onshore sediment transport
	Erosive Conditions	Increased offshore sediment transport

Baldock *et al.* (2010) ascribed the results to a change in relative sediment fall velocity. Relative sediment fall velocity is the wave height (m) divided by the product of the fall velocity (m/s) and wave period (s). Free long waves reduce the relative sediment fall velocity resulting in accretion, where the opposite is true for bound long waves. Baldock *et al.* (2011) attributed the impact of long waves on the cross-shore sediment transport to the rise in water level and thus to the landward movement of the shoreline and breaker point.

Cácares & Alsina (2016) suggested that long waves increase the wave breaking area based on large wave tank experiments conducted in Barcelona, Spain. The sediment transport region is widened in the process, resulting in increased sediment transport due to infra-gravity waves.

Tsunami-like waves have a significant impact on beach profiles. Erosion and accretion primarily occurs due to sheet flow when the wave retreats from the shoreline (Chen *et al*., 2012). Li and Huang (2013) concluded that both Xbeach and Delft3D predict tsunami-induced sediment transport very well for laboratory experiments. When these models were, however, used for correlation with the 2004 tsunami event in Indonesia, very poor results were obtained.

2.7 TYPICAL OFFSHORE WAVE CONDITIONS

In order to set up different wave conditions, a general understanding of typical offshore wave conditions is required. Currently, the Beaufort wind scale (and accompanying sea state conditions) is the universal guide to classifying the different wave conditions under different wind states (Met Office, 2016). From the Beaufort scale typical offshore wave heights under calm, moderate and storm conditions can be estimated. Table 2-8 provides the descriptions of the sea states of the Beaufort wind scale.

Table 2-8: Description of Sea States of the Beaufort Wind Scale (Met Office, 2016)

Sea State	Description	Probable Wave Height (m)	Probable Max Wave Height (m)
0	Calm (Glassy)	-	-
1	Calm (Rippled)	0.1	0.1
2	Smooth (Wavelets)	0.2	0.3
3	Slight	0.6	1.0
3-4	Slight-Moderate	1.0	1.5
4	Moderate	2.0	2.5
5	Rough	3.0	4.0
5-6	Rough-Very Rough	4.0	5.5
6-7	Very Rough-High	5.5	7.5
7	High	7.0	10.0
8	Very High*	9	12.5
8	Very High**	11.5	16
9	Phenomenal	14+	-

* With storm wind conditions

** With violent storm wind conditions

2.8 Main Conclusions from Literature Review

Literature regarding cross-shore beach profiles, water level variation, storm duration and long waves were reviewed. The most important information obtained from the literature study, was the conclusions of previous studies on how water level variation, storm duration and long waves influence cross-shore beach profile evolution.

In Section 2.6.2.2, previous studies on the effect of sea level variation on cross-shore beach profile evolution were discussed. Although studies have been done on long-term sea level rise, the focus of this study was short-term impact. Studies investigating the effect of tidal variation on cross-shore beach profiles concluded that tidal variation on its own, does not cause significant cross-shore sediment transport. Tidal variation does, however, shift the position of wave impact on the beach face cyclically.

The results of studies on the difference in cross-shore beach profile impact between constant storm wave conditions with different durations, were discussed in Section 2.6.3.2. From previous studies, it was concluded that storms with longer storm durations cause more erosion of the cross-shore beach profile than storms with shorter durations. If the duration of storm impact is already long enough that a near equilibrium beach profile have been developed, the cross-shore beach profile response of storms with longer storm durations, will not differ significantly. A storm with a short duration will, however, initiate cross-shore beach profile change that is significantly different from a storm with a different storm duration, that is still relatively short. The reason for this observation is that beach profiles erode rapidly when storm wave conditions occur, but over time the rate of cross-shore beach profile change, decreases as the beach profile develops to reach an equilibrium state under the specific wave conditions.

Section 2.6.4.2 provides insight on the finding of previous studies regarding the impact of long waves on cross-shore beach profiles. Contradicting conclusions have been drawn on whether long waves have an influence on offshore bar formation or not. Quantitative studies have concluded that free and bound long waves influence cross-shore beach profile response, predominantly due to the varying water levels and widened sediment transport region induced by long waves. The effect of free long waves on cross-shore beach profile development is less significant than the effect of bound long waves.

3 METHODOLOGY

3.1 RESEARCH METHODOLOGY

The purpose of this study was to determine what the effects of sea level variation, storm duration and long waves are on cross-shore beach profile evolution. In addition to this, three cross-shore numerical models were selected to determine whether one or all of the selected cross-shore numerical models could be used to accurately predict quantitative beach profile response due to water level variation, storm duration and long waves. In order to ensure sufficient knowledge on important topics involved in this study, a literature study was done. Through the literature study an understanding of the key concepts of the study was obtained as well as information on how similar past studies have been conducted and what the results were. The literature study also provided information that was used to assist in the development of the numerical model set-ups.

Three numerical models to model cross-shore sediment transport were selected. The first part of the process was to analyse these numerical models and their sensitivity to sea level variation, storm duration and long waves.

An effort was made to obtain sufficient physical site and prototype flume data that included wave data, sediment properties and corresponding beach morphology. From the available data, cases specific to sea level, storm duration and long waves were extracted and the cross-shore erosion and accretion of the beaches were determined.

The extracted wave data, sediment data and beach profiles before the impact of sea level, storm duration and long waves on beaches were programmed into the numerical models. Cross-shore erosion and accretion were determined for the extracted cases through the numerical models.

The final part of the process was to determine whether numerical models can accurately model the effect of sea level, storm duration and long waves on cross-shore beach profiles. This was done by comparing the physical data to the modelled data. The most accurate model of the three selected sediment transport models was identified for each of the impacts (sea level, storm duration and long waves). The whole research and study process is schematised in Figure 3-1.

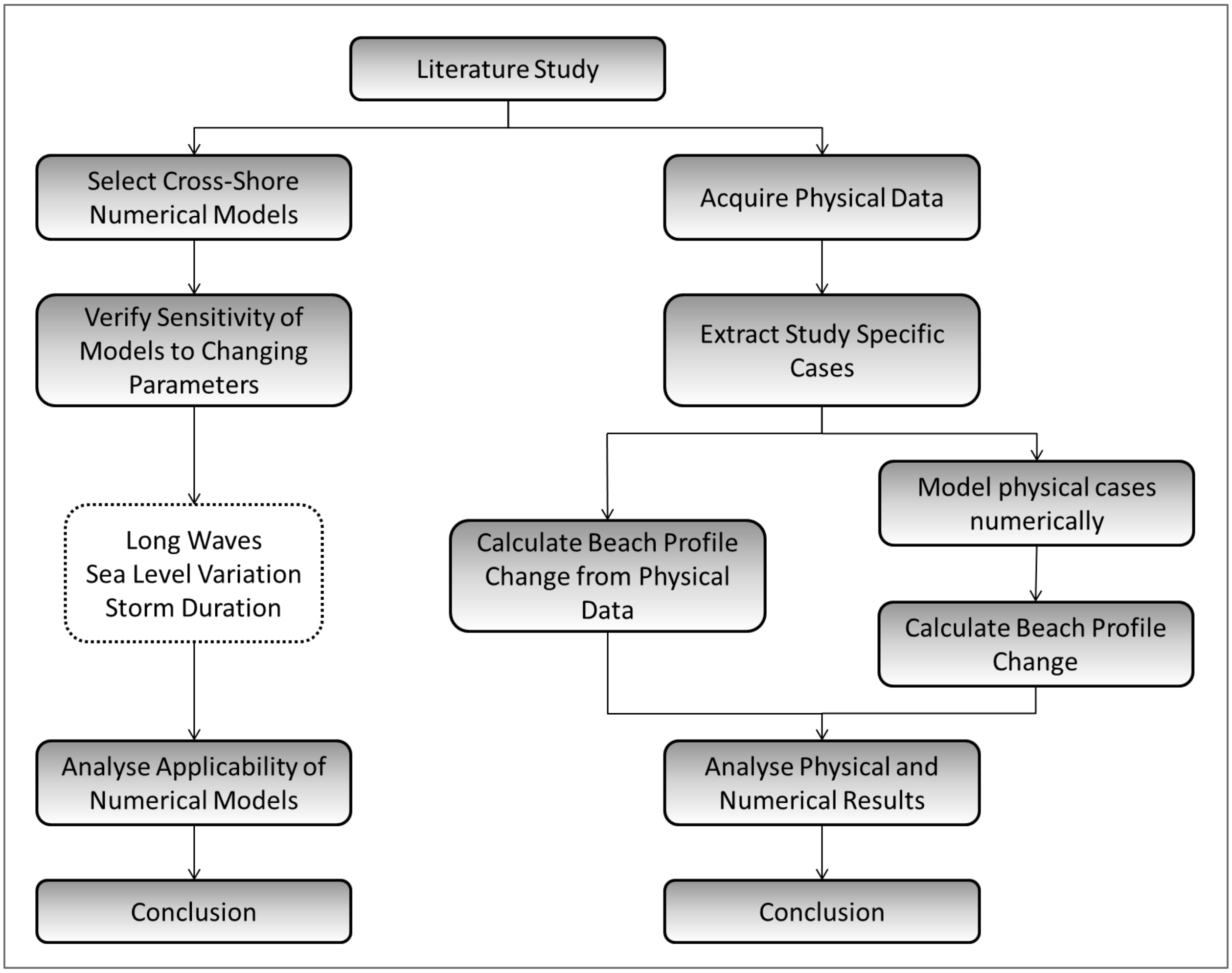


Figure 3-1: Schematic Representation of Research Methodology

3.2 Sensitivity of Model Beach Profile Response to Changing Parameters

Three cross-shore sediment transport models were selected. Not all of these models are necessarily sensitive to all three of the changing parameters, namely sea level variation, storm duration and long waves. The responses of each model towards changes in each of the above mentioned parameters were studied. The results of the model sensitivity analyses were plotted and the graphs were analysed in order to verify sensitivity of the models.

In order to verify model sensitivity to sea level variation, 11 model runs for three wave conditions (with different severities) were respectively done per model. Each of the 11 runs per wave condition had different sea levels varying between -5m and +5m to mean sea level. The total time of impact was 12 hours for each model run.

Figure 3-2 schematises the model runs to determine the sensitivity of the three selected numerical sediment transport models to sea level variation. The model set-up for the sea level variation sensitivity analysis is further discussed in Section 5.4.2.

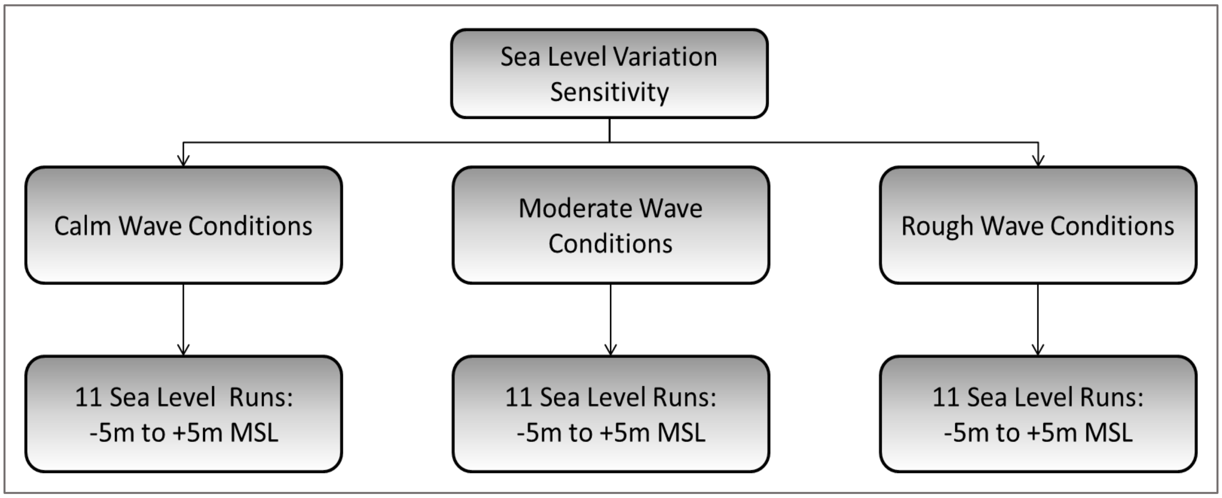


Figure 3-2: Model Runs to Determine Model Sensitivity to Sea Level Variation

Model sensitivity to storm duration was tested by analysing the effect of constant storm wave conditions for 15 different storm durations (12 to 96 hours). The different storm durations were modelled for two different storm conditions: one mild storm and one severe storm. Figure 3-3 schematises the model runs to determine the sensitivity of the three selected numerical models to storm duration. The model set-up for the storm duration sensitivity analysis is further discussed in Section 5.4.3.

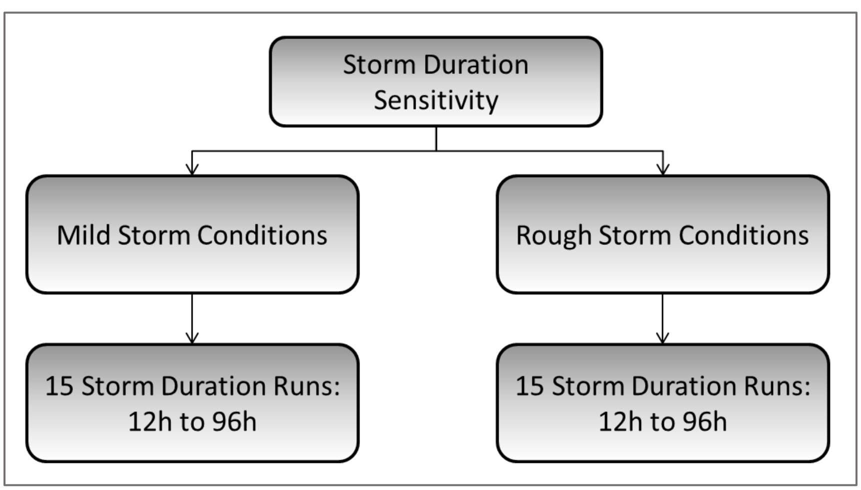


Figure 3-3: Model Runs to Determine Model Sensitivity to Storm Duration

Long wave sensitivity of models was tested for free long waves combined with monochromatic short waves as well as for bichromatic wave groups. For the free long wave sensitivity study, the model outcomes of the three different monochromatic wave conditions at mean sea level from the water level variation sensitivity study were used for comparisons. Three new model runs were done per wave condition, with each model run having a different free long wave period. The model outcomes of the monochromatic plus added free wave runs were compared with the outcomes of the three monochromatic wave conditions. If a significant difference was observed between the beach profile response to the monochromatic waves and monochromatic waves with free long waves, it indicated that the numerical model is sensitive to free long waves.

When the sensitivity of the models to bound long waves forced by bichromatic waves were determined, the same three monochromatic wave conditions were used as for the free wave sensitivity analysis. Three model runs were done per wave condition, with each model run having a different bound long wave period. The bound long waves were generated by defining bichromatic wave conditions with the same mean wave energy and energy flux as the monochromatic wave conditions. The response of the beach profiles to the bichromatic wave conditions were compared to the beach profile response to monochromatic wave conditions. If a significant difference was observed between the beach profile response to the monochromatic waves and bichromatic waves, it indicated that the numerical model is sensitive to bound long waves. Figure 3-4 schematises the model runs to determine the sensitivity of three selected numerical models to free and bound long waves. The model set-up for the long wave sensitivity analysis is further discussed in Section 5.4.4.

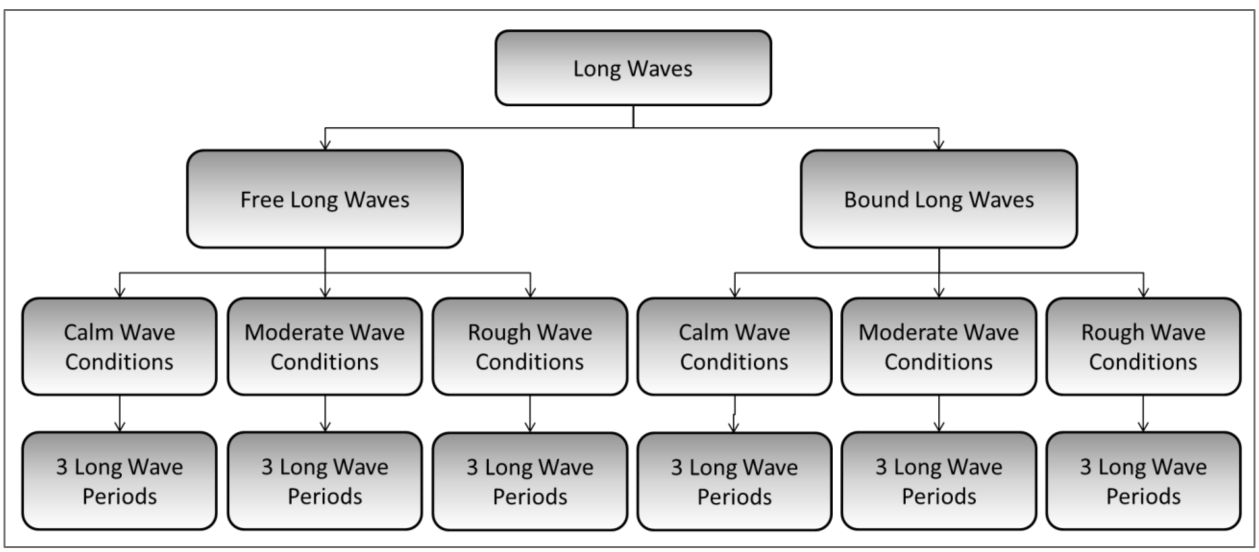


Figure 3-4: Model Runs to Determine Model Sensitivity to Long Waves

Table 3-1 summarises the dependent, independent and constant variables used to determine the sensitivity of the different models to sea level variation, storm duration and long waves respectively.

Table 3-1: Variables to Determine Sensitivity of Numerical Models to Changing Parameters

<table>
<tr><th colspan="2">Independent Variable</th><th>Dependent Variable</th><th>Constants</th></tr>
<tr><td colspan="2">Sea Level (m)</td><td rowspan="4">Numerical Model Beach Profile Response</td><td>Sediment Properties
Initial Beach Profile
Wave Conditions
Duration of Impact</td></tr>
<tr><td colspan="2">Storm Duration (h)</td><td>Sediment Properties
Initial Beach Profile
Wave Conditions
Sea Level</td></tr>
<tr><td rowspan="2">Long Wave Period (s)</td><td>Free long waves amongst monochromatic short waves</td><td>Sediment Properties
Initial Beach Profile
Monochromatic Wave Conditions
Sea Level
Duration of Impact</td></tr>
<tr><td>Bichromatic wave group</td><td>Sediment Properties
Initial Beach Profile
RMS Wave Height & Energy Flux
Sea Level
Duration of Impact</td></tr>
</table>

3.3 Assessment of Numerical Model Beach Profile Response Accuracy

After the sensitivity of the models to changing water levels, storm durations and long waves was analysed, the accuracy of the models was assessed. In order to assess the models, physical data was obtained. The numerical models were calibrated for a specific data set after which the models were set up to model the same scenarios as the physical data. The modelled results were compared statistically, volumetrically and visually to verify the accuracy of the numerical model responses. The general verification process is schematised in Figure 3-5.

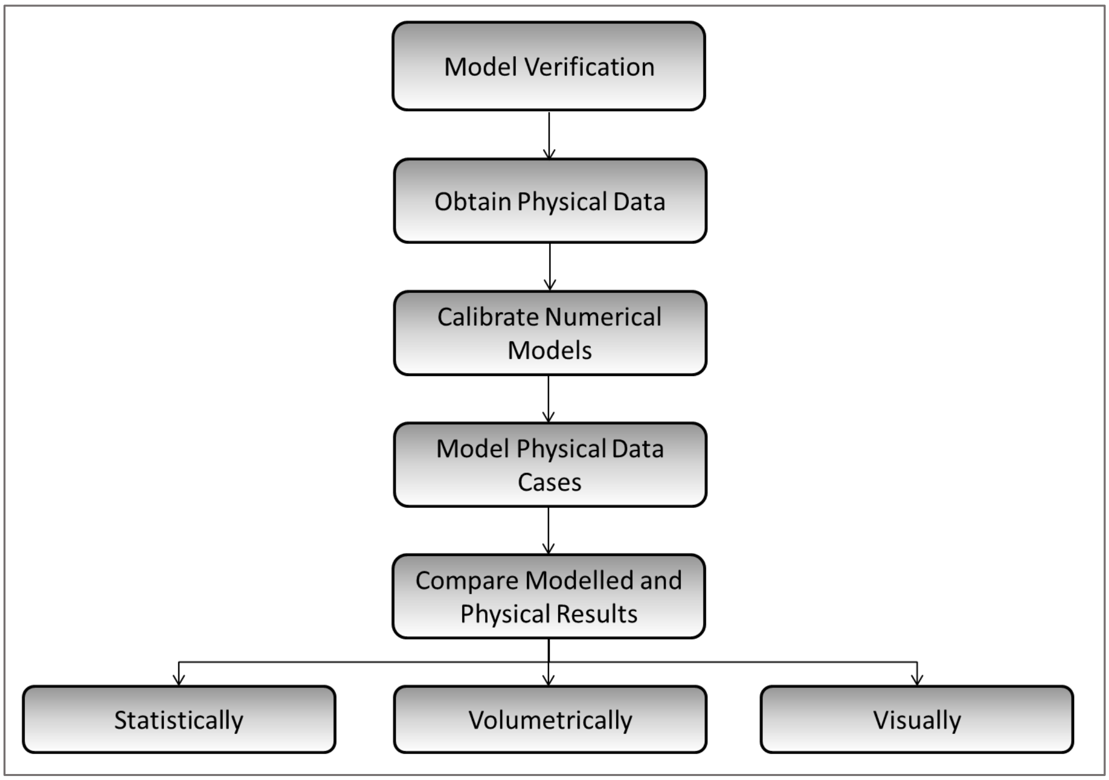


Figure 3-5: General Approach to Verify Model Accuracy

For a specific parameter under analysis (water level variation, storm duration or long waves), the independent variables for the assessment of the model accuracy were the respective numerical models. The different numerical models were set up with the same input data, which were regarded as the constants in this process. The dependent variable was the accuracy of the numerical model beach profile response to the input data.

4 Physical Data Employed

4.1 Acquisition of Physical Data

In order to assess the accuracy of the selected numerical models studied in this thesis, physical data relating to water level variation, storm duration and long waves had to be obtained. After researching applicable data sources, the data was requested from the data holders. The list of data that were obtained is provided in Table 4-1, along with a brief summary of the data.

Table 4-1: Summary of Physical Data Available for Assessment of Model Accuracy

Data	Dates	Brief Description
Coastal Engineering Research Center (CERC) Field Research Facility	1982-1991	Wave, water level, wind and morphology field data were recorded at the Field Research Facility (Duck, North Carolina, USA) on a bi-weekly basis. (Howd & Birkemeier, 1987)(Lee & Birkemeier, 1993)
Coastal Engineering Research Center (CERC) Large Wave Tank	1957-1957, 1962	Experiments were done in the Dalecarlia Reservation Large Wave Tank (Washington, District of Columbia, USA) to investigate cross-shore beach profile response under monochromatic storm wave conditions. (Kraus & Larson, 1988)
Large Installation Plan (LIP) 11D Delta Flume Experiments	1993	Large wave tank experiments were done in the Delft Hydraulics Delta Flume (Netherland) to study the effects of narrow random waves on cross-shore beach profiles response. (Roelvink & Reniers, 1995)
Narrabeen-Collaroy Beach Historical Survey Program	1976-2016	Field data have been surveyed at Narrabeen Beach (Australia). Beach morphology, wave and wind characteristics were surveyed approximately once a month. (Turner *et al*., 2016)
Swash Zone Response under Grouping Storm Conditions (SUSCO)	2009	Prototype-scale experiments investigating the effect long waves/wave groups on cross-shore beach profile response in the Canal d'Investigació i Experimentació Marítima, Barcelona, Spain. (Vicinanza, 2011)
Water-Interface-Sediment Experiments (WISE)	2013	Beach morphology and sediment suspension surveys were done in the Grosser Wellenkanal (large wave tank in Germany) under erosive and accretive conditions. (Vousdoukas, 2013)

Not all of the available data were used to assess the accuracy of the numerical models in predicting cross-shore beach profile response to varying water levels, storm duration and long waves respectively. The rest of this chapter discusses the selected physical data that were used for the different studied parameters and the reason for the specifically selected data.

4.2 WATER LEVEL VARIATION PHYSICAL DATA

From all the available data, water level variation was only observed in the field data and CERC Large Wave Tank data. In order to assess the beach profile response due to water level variation using field data, the wave conditions must be relatively constant. This way, the impact of water level variation on cross-shore beach profile change is more significant than when other varying factors must also be accounted for. The field data from Narrabeen beach were immediately disregarded, since the time between consecutive surveyed beach profiles were too long. The large amount of time between consecutive profiles allowed for significant variance in wave patterns, that were not desired in this analysis. It was possible to extract data from the CERC Field Research Facility in Duck, USA, where the wave conditions between consecutive measured beach profiles remained relatively constant. However, two problems arose after the data were analysed in more detail. Firstly, the tidal variation was provided in small graphs, which made it difficult to accurately read off the measured water level variations. The second problem was the lack of wave direction data. The only viable data that remained to be utilised in the assessment of the model accuracy in predicting beach profile change due to water level variation, was the CERC Large Wave Tank data.

Kraus & Larson (1988) reported the results of large wave flume experimental studies from 1962 in order to supplement the experimental studies conducted by Saville (1957). The experimental studies were done to increase the understanding of beach profile response to different hydrodynamic conditions. Kraus & Larson’s (1988) experiments were conducted in the Large Wave Tank that was part of the Coastal Engineering Research Center’s (CERC) research facilities. The Large Wave Tank was a concrete structure 194m in length, 4.5m in width and 6.1m deep. The waves in the Large Wave Tank were generated with a wave generator mounted on a rail over the Large Wave Tank. The maximum operational wave height was 1.82m, but wave heights sometimes increased to 3m at the point of breaking. This led to occasional spillage over the tank walls.

Case 911 was the only experimental study done by Kraus & Larson (1988) that included water level variation and was therefore chosen as the case to which the numerical models were compared. The generated wave conditions in Case 911 were constant with a wave height of 1.34m and a wave period of 7.87s. The temperature of the water was estimated as 26°C (Kraus & Larson, 1988) and the quartz sand had a median diameter of 0.4mm.

The water level was varied cyclically in a stepwise manner (Kraus & Larson, 1988) in order to imitate a tide with a 12-hour period. The water level variation over the total experimental time, as provided by Kraus & Larson (1988), is shown in Figure 4-1.

During the course of the experimental study, intermediate profiles were recorded every 3 to 6 hours, resulting in 11 measured profiles. The times at which the intermediate profiles were recorded, are tabulated in Table 4-2. The survey times are also indicated in Figure 4-1 as dotted lines.

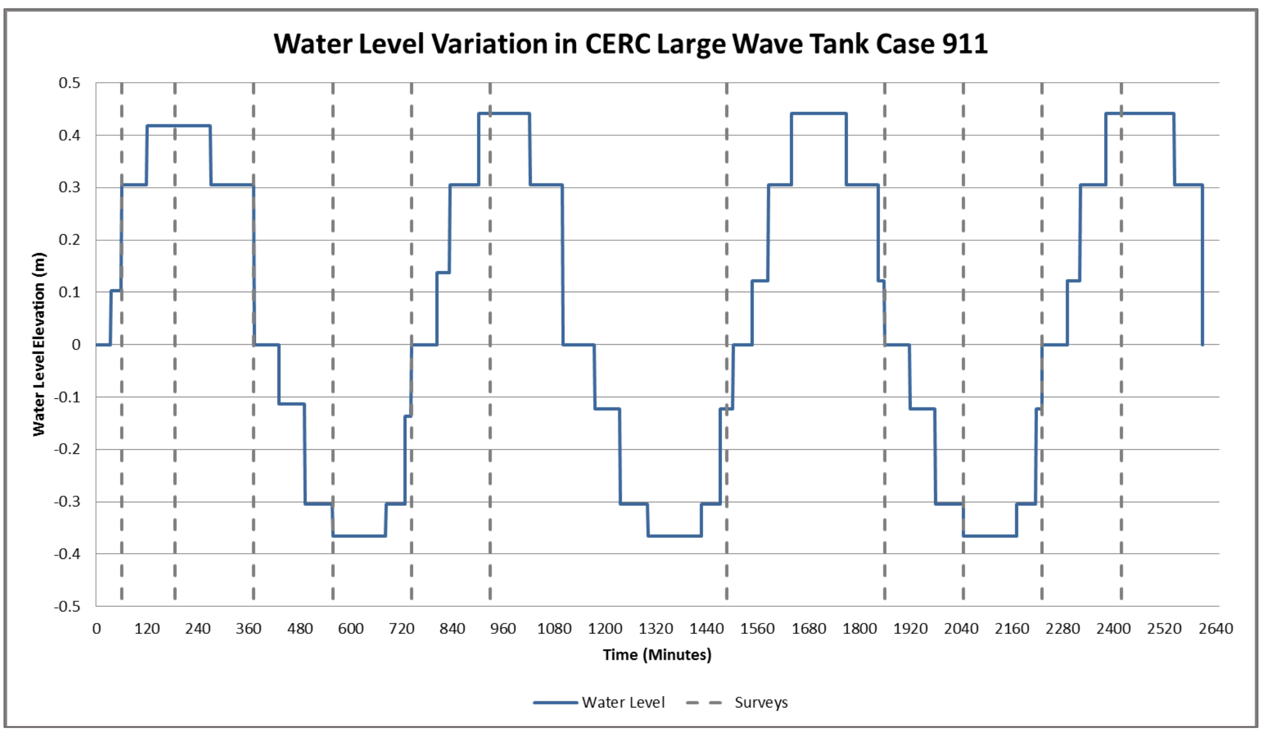


Figure 4-1: Water Levels over Time Span of CERC Case 911 (Kraus & Larson, 1988)

Table 4-2: Times at which Profiles were Measured for CERC Case 911

Intermediate Profile	Time
1	1.0h
2	3.1h
3	6.2h
4	9.3h
5	12.4h
6	15.5h
7	24.8h
8	31.0h
9	34.1h
10	37.2h
11 (final)	40.3h

4.3 Storm Duration Physical Data

Initially physical site data were studied in order to extract storm events that had different durations, but more or less the same significant and maximum wave heights, as well as the same wave period and direction. Continuous wave, weather and beach profile data have been recorded at Narrabeen Beach, Australia. The data is available from 1976 to 2016. After all the storms, with more or less the same wave conditions, but different durations were extracted, the beach profiles measured before and after the storms were extracted. Unfortunately, it was found that the initial and final profiles were not surveyed often enough to provide a clear indication of the impact of the storms. Typically, the profiles were measured on a monthly basis, with hardly any profiles recorded within two days from the beginning or end of a storm. It was therefore concluded that the Narrabeen data is not sufficient to study short term beach profile response under different storm durations as is necessary in this study.

Physical site data from Duck, North Carolina, United States of America, were also considered as a data source to verify the accuracy of the numerical models in predicting beach profile response to storms with different durations. Although beach profiles were surveyed quite often, the electronic database was under construction at the time of this study. Only 1982 to 1991 data provided in reports by Howd & Birkemeier (1987) and Lee & Birkemeier (1993) were available. The lack of wave directions in these reports; however, made the data sets unusable for this study. It could not be assumed that the waves approached the beach perpendicularly, since research suggested that the dominant wave directions are typically between 30 to 60 degrees to the perpendicular at Duck (USACE, 2009).

Due to a lack of physical site data, it was decided to approach the storm duration model assessment study in the same manner as the storm duration sensitivity study, where the impact of monochromatic storm wave conditions over different durations were studied. With this approach, any prototype wave tank data could have been used if the durations of the experiments were long enough to represent storm durations of more than 24 hours and if sufficient intermediate profiles were surveyed to represent shorter storm durations. The wave conditions and beach profile response had to be erosive, since storm conditions were studied.

The durations of the LIP experimental runs varied between 12 hours and 18 hours with few intermediate profiles surveyed after 10 hours. The LIP experimental run times were thus not long enough to represent a wide variety of storm durations and were therefore not used to assess the model accuracy in predicting beach profile change under different storm durations. The WISE experiments posed a similar problem concerning the duration of the experimental runs. Five experimental runs were done under erosive wave conditions, but the maximum experimental run duration was only 7.25 hours, which was too short to use in the assessment of the model accuracy in predicting cross-shore beach profile change due to different storm durations.

The data obtained from the experimental studies in the CERC Large Wave Tank, as provided by Kraus & Larson (1988), were used to verify the accuracy of the numerical models in predicting the effect of storm duration on beach profile evolution. The CERC Large Wave Tank data was applicable to this study, since the experimental runs lasted at least 30 hours and sufficient intermediate profiles were surveyed. Five erosional experimental cases were extracted based on the least amount of wave reflection that occurred in the tank. The cases were also selected to represent different wave conditions (different wave heights and periods) and two different median sediment sizes. Table 4-3 provides a summary of the selected experimental runs.

Monochromatic wave conditions were assumed, even though Kraus & Larson (1988) never explicitly stated it in the report. The wave heights were measured at the toe of the beach.

Table 4-3: Summary of Selected CERC Large Wave Tank Cases for Storm Duration Verification

Case	D_{50} (mm)	Wave Height (m)	Wave Period (s)	Temperature (°C)	Total Duration (h)	Number of Profiles
300	0.22	1.68	11.33	5	50	10
400	0.22	1.62	5.6	7	40	9
500	0.22	1.52	3.75	6	100	15
401	0.4	1.62	5.6	18	66	12
501	0.4	1.52	3.75	26	60	11

4.4 Long Wave Physical Data

Although long waves occur in reality and thus have an influence on the beach profile responses in the field, it was not possible to identify the effect of the long waves separately from overall wave data. The SUSCO data was the only physical data that could be used to analyse the effects of long waves individually. Cáceres & Alsina (2016) used the SUSCO large wave tank experiments to improve the understanding of the effect of free and bound long waves on beach profiles. The experimental runs were done in the Canal d'Investigació i Experimentació Marítima (CIEM large-scale wave flume) at the Universitat Politècnica de Catalunya (UPC) in Barcelona.

The flume has a length of 100m, a depth of 4.5m and a 3m width. A wave-maker was placed 43m from the toe of the beach. The same still-water level (depth of 2.5m) was used in all the experimental runs. The sediment properties were consistent for all the experimental runs, with a median diameter (d_{50}) of 0.25mm. The grain size distribution was narrow (d_{10} = 0.154mm and d_{90} = 0.372mm). All the initial beach profiles had a slope of approximately 1:15, but the slopes varied slightly between the different runs. The temperature was measured for all the experimental runs, but was not available. A constant settling velocity for all the experimental runs was, however, provided as 0.034m/s.

Thirteen experimental runs were done for different wave combinations. Four of the thirteen runs were random wave runs and were not included in this study. Two of the experimental runs were done with monochromatic waves, three were done with combinations of free long waves and monochromatic waves (referred to as combination waves) and another four runs were done with bichromatic waves.

Table 4-4 provides a summary of the wave conditions of the experimental runs (excluding the four random wave cases). Initial and final profiles (after 138 minutes) were surveyed along with three intermediate profiles after estimated times of 23, 46 and 92 minutes respectively.

Table 4-4: Experimental Runs Evaluating the Effect of Long Waves on Beach Profiles by Cácares & Alsina (2016)

Run	**Short/Primary Wave Condition**		**Long/Secondary Wave Condition**		**Wave Type**
	Height (m)	Period (s)	Height (m)	Period (s)	
M_E	0.37	3.7	-	-	Monochromatic
C_E4	0.37	3.7	0.04	15	Combination
B_E1	0.26	3.9	0.26	3.5	Bichromatic
B_E2	0.26	4.2	0.26	3.3	Bichromatic
M_A	0.23	6	-	-	Monochromatic
C_A2	0.23	6	0.04	30	Combination
C_A4	0.23	6	0.04	15	Combination
B_A1	0.16	5.4	0.16	6.6	Bichromatic
B_A2	0.16	4.6	0.16	7.1	Bichromatic

5 CROSS-SHORE SEDIMENT TRANSPORT NUMERICAL MODEL STUDY

5.1 SELECTION OF MODELS

Bruun's (1962) cross-shore sediment transport model is a static model and one of the oldest models to predict cross-shore sediment transport. Other static models include those developed by Edelman (1972) and Dean (1991). Static models do not consider hydrodynamic and sediment dynamic processes, therefore, they are not reliable in the prediction of cross-shore sediment transport rates (Velegrakis, 2012). For this reason, static models are not considered for the prediction of cross-shore transport rates in this study.

Apart from static cross-shore sediment transport models, dynamic models based on analytical, empirical, semi-empirical and process-based approaches also exist. Table 5-1 provides a summary of some popular dynamic cross-shore sediment models.

Table 5-1: Summary of some widely used cross-shore morphological models

Model	Developer	Approach
EDUNE	Kriebel (1986)	Analytical
DurosTA	Steetzel (1993)	Process-Based
SBEACH	Larson & Kraus (1989)	Empirical
CROSMOR2007	Van Rijn (2007)	Process-Based
CSHORE	Kobayashi (2009)	Process-Based
XBEACH	Roelvink *et al*. (2009)	Process-Based
C2Shore	Grzegorzewski *et al.* (2013)	Process-Based
DELFT3D	Delft Hydraulics	Process-Based
Unibest	Delft Hydraulics	Process-Based/Empirical

Most of the models mentioned in Table 5-1 are open-source, therefore, they were viable to be chosen as one of the models used in this study. Notice should be taken that DELFT3D and Unibest are not essentially cross-shore numerical models, but can include cross-shore sediment transport modelling as part of the overall model suites. It was decided that at least two of the three models should be based on different approaches.

EDUNE and SBEACH are the only models mentioned in Table 5-1, that are not process-based. Although EDUNE is not necessarily less accurate than SBEACH, EDUNE was outdated as a numerical cross-shore sediment model once SBEACH was developed (Fauver, 2005). EDUNE also does not model sediment transport beyond the breaker depth, where sediment transport still occurs (Schoonees & Theron, 1995). Therefore, the first model that was chosen for this study, was the SBEACH model.

The selection of a process-based model was a little more complicated. Delft3D and Unibest were not selected, because they are not pure cross-shore sediment transport models and the complexity of the model set-up was not desirable. CROSMOR2007 is not open-source and therefore not considered for selection. C2Shore is an extended version of CSHORE that includes the ability to incorporate longshore sediment transport. CSHORE is an open-source model, but no download links of the C2Shore model were found at the time of this study and it was assumed that C2Shore is not and open-source model. Both CSHORE and XBEACH remained viable options. XBEACH was finally selected as the second model that was analysed in this study. The reasons for this selection were that XBEACH is one of the most widely used processed-based models, it is an open-source model and it has the ability to solve bound long waves and predict their influence on cross-shore beach profiles. It was assumed that CSHORE does not solve long waves, since no reference was made to this function in the CSHORE Model Documentation (Kobayashi, 2009).

After some research was done on the remaining models, it was found that Van Rijn (2007) developed a simplified model (DUNERULE) based on the CROSMOR2007 model. Although DUNERULE does not model beach profile response below the water level and only models erosional cases, it is an extremely simple model and well verified for storm conditions. Therefore, DUNERULE was chosen as the third model to see whether simpler models can also effectively predict set-back lines and dune erosion.

5.2 Theoretical Principles of Selected Models

5.2.1 SBEACH

SBEACH is a numerical sediment transport model based on semi-empirical relationships. The empirical relationships in this model were based on data generated through large wave tank experiments. In this section a summary of the theoretical background of SBEACH is given based on information found in:

- "SBEACH: Numerical Model for Simulating Storm-Induced Beach Change - Report 1" by Larson & Kraus (1989)
- "SBEACH: Numerical Model for Simulating Storm-Induced Beach Change - Report 2" by Larson *et al.* (1990)

The main concept on which this sediment transport model is based is that cross-shore beach profile change occurs due to the energy produced by breaking waves. Local wave energy, water level and beach profile properties are thus the governing properties for beach profile change prediction using SBEACH. Figure 5-1 schematizes the outline according to which the SBEACH numerical model calculates beach profile change.

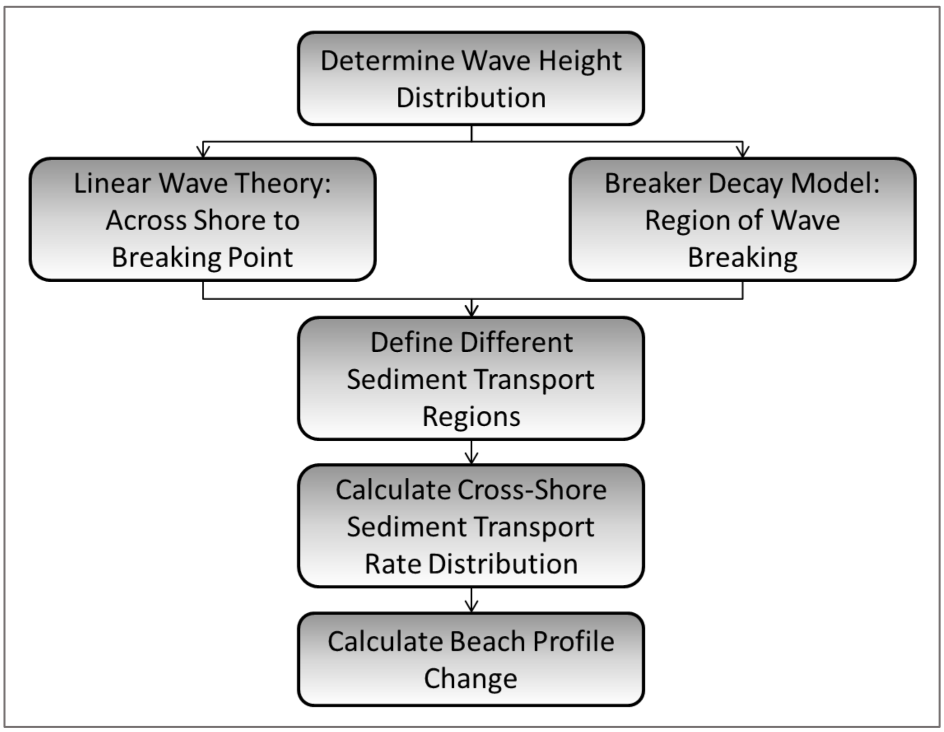


Figure 5-1: Basic Structure of SBEACH Numerical Model

Wave Theory and Model

Linear wave theory was applied across the shore to the breaking point to determine the wave height distribution before wave breaking takes place. The model approach to determine the point at which wave breaking takes place was based on data obtained from the CRIEPI large wave tank experiments (Kajima *et al*., 1982) as well as small-scale laboratory experiments (Smith & Kraus, 1988). The breaker index calculated using the SBEACH model is equated using the following formula:

$$\frac{H_b}{h_b} = 1.14\left(\frac{tan\beta}{\sqrt{H_0/L_0}}\right)^{0.21} \tag{4.1}$$

Where,

- H_b is the wave height of the wave just before breaking (m)
- h_b is the depth at which wave breaking takes place (m)
- $tan\beta$ is the bottom beach slope one third of the local wave length seaward of the breaking point
- H_0 is the deep water wave height (m)
- L_0 is the deep water wave length (m)

Breaker decay in the surf zone after wave breaking took place was based on a breaker decay model derived by Dally (1980). The model was compared with the CRIEPI wave height distributions to ensure adequate performance of the breaker decay model. The CRIEPI data was also used to estimate the empirical values in the model. The equation governing breaker decay is based on conservation of wave energy flux:

$$\frac{dF}{dx} = -\frac{\kappa}{h}(F - F_S) \tag{4.2}$$

Where,

- F is wave energy flux (N/s)
- x is a cross-shore coordinate, originating from the breaking point (m)
- κ is an empirical wave decay coefficient (-)
- h is the water depth (m)
- F_S is the stable wave energy flux (N/s)

Wave set-up and set-down caused by variation in radiation stress were incorporated into the model using the following equation:

$$\frac{dS_{xx}}{dx} = -\rho g(h + \eta)\frac{d\eta}{dx} \tag{4.3}$$

Where,

- S_{xx} is the radiation stress component directed onshore, calculated using: $S_{xx} = \frac{3}{16}\rho g H^2$
- ρ is the density of the water (kg/m^3)
- g is the gravitational acceleration (m/s^2)
- h is the water depth excluding set-up/set-down (m)
- H is the wave height (m)
- η is the wave set-up or set-down (m)

Energy in the surf zone is mainly dissipated through wave breaking. Energy dissipation is, however, also caused by bottom friction. SBEACH calculates energy dissipation caused by bottom friction using the same approach as Dally (1980). This approach uses linear wave theory to determine horizontal orbital velocity, from where shear stress is determined assuming it is proportional to horizontal orbital velocity squared.

Sediment Transport Theory and Model

The boundaries of the total region in which sediment transport takes places are positioned at the seaward point where no significant sediment movement takes place and at the landward position where the wave run-up limit is. Between the two boundaries for sediment transport, four sediment transport zones are classified based on the wave distribution. These zones are tabulated in Table 5-2.

Table 5-2: Classification of SBEACH Transport Zones

Zone Number	Zone Name	Zone Definition
I	Pre-breaking Zone	This zone extends between the seaward boundary of sediment transport and the wave breaking point.
II	Breaker Transition Zone	This is the zone between the wave breaking point and the plunge point. Based on data
III	Broken Wave Zone	This zone is between the plunge point and the wave reformation point or swash zone.
IV	Swash Zone	The zone extends from the beginning of the swash zone to the landward limit of wave run-up.

The sediment transport rate distributions seaward and shoreward of Zone III are calculated using semi-empirical relationships derived from large wave tank experiments performed by Saville (1957), Caldwell (1959) and Kraus & Larson (1988). The transport rates in all the zones depend on the calculated transport rates of Zone III. The sediment transport rate distributions in Zone III were based on transport rate formulas used by Moore (1982) and Kriebel (1982), with an added term to account for the slope of the beach. Table 5-3 supplies the equations used to calculate the transport rate distributions in the different transport zones.

Table 5-3: Transport Zone Sediment Transport Distribution Rates

Zone	Equation	Definition of Parameters
I	$q = q_b e^{-\lambda(x-x_b)}$	q_b is the transport rate at the breaking point λ is the spatial decay coefficient x_b is the location of the breaking point
II	$q = q_p e^{-0.2\lambda(x-x_p)}$	q_p is the transport rate at the plunging point λ is the special decay coefficient x_p is the location of the plunging point
III	$q = \begin{cases} K\left(D - D_{eq} + \frac{\varepsilon}{K}\frac{dh}{dx}\right); & D > D_{eq} - \frac{\varepsilon}{K}\frac{dh}{dx} \\ 0; & D < D_{eq} - \frac{\varepsilon}{K}\frac{dh}{dx} \end{cases}$	K is the empirical transport rate coefficient D is the wave energy dissipation per unit volume D_{eq} is the equilibrium energy dissipation per unit volume ε is the transport rate coefficient for the slope dependent term h is the still water depth (m)
IV	$q = q_z \left(\frac{x - x_r}{x_z - x_r}\right)$	q_z is the transport rate at the end of Zone III x_r is the distance to the end of Zone IV x_z is the distance to the end of Zone III

Sediment transport can either be directed onshore (accrete) or offshore (erode). The direction of sediment transport is predicted using equation 4.4. If the left side of the equation is larger than the right side, the profile is accreting and *vice versa*.

$$\frac{H_0}{L_0} = M\left(\frac{H_0}{wT}\right)^3 \tag{4.4}$$

Where,

- M is an empirically determined coefficient with a value of 0.0007
- w is the sand fall speed (m/s)
- T is the wave period (s)
- L_0, H_0 is the deep water wavelength (m) and wave height (m)

Calibration and Verification of Model

The numerical model was calibrated and verified during the model development phase using the data from Kraus & Larson's (1988) large wave tank experiments as well as field data collected at Duck, North Carolina. Although the model was developed with the knowledge that long waves may have a significant impact on cross-shore sediment transport, the contribution of long waves to sediment transport was not incorporated in the model (Larson & Kraus, 1989). The reason for this was a lack of quantitative engineering relations to predict the effect of long waves and wave groups on sediment transport. Larson & Kraus (1989) used one of the CERC Large Wave Tank cases (Kraus & Larson, 1988) to verify the ability of SBEACH to predict cross-shore beach profile evolution under varying water levels. It was found that the qualitative development of the beach profile under varying water levels was well predicted. However, quantitatively, the location of the offshore bar was predicted too far seaward and the model did not predict the observed berm formation in the measured data (Larson & Kraus, 1989).

Since the release of SBEACH, many researchers have used SBEACH to predict cross-shore sediment transport and verified SBEACH's performance. Schoonees & Theron (1995) concluded that SBEACH is a stable numerical model that predicts cross-shore beach profile evolution reasonably well. Although the model did not necessarily provide accurate quantitative predictions, the sediment transport trends were quite accurate. SBEACH lacks the ability to predict berm and bar through formations well, possibly because of the poor empirical equation to predict the net sediment transport direction (Schoonees & Theron, 1995). Schoonees & Theron (1995) listed the lack of inclusion of long waves in the wave model as a disadvantage.

Thieler *et al.* (1999) found that one of the biggest problems in the SBEACH model set-up is the empirical equation to predict the net sediment transport direction. It was found that the method by which the empirical equation was set up, was not very accurate. The poor net sediment transport direction predictor may result in poor model predictions especially for accretive wave conditions, since the model has not been extensively verified for accretional cases.

5.2.2 XBEACH

XBEACH is a process-based numerical transport model that is capable of modelling both long-shore and cross-shore sediment transport. In this section a summary of the theoretical background of XBEACH is given based on information found in the XBEACH Manual (Deltares, 2015).

Although intra-wave sediment transport occurs, because of wave asymmetry and skewness, XBEACH is modelled on the principle that the sediment transport caused by long waves and mean currents is much more significant. A rough schematization of the XBEACH model approach is provided in Figure 5-2.

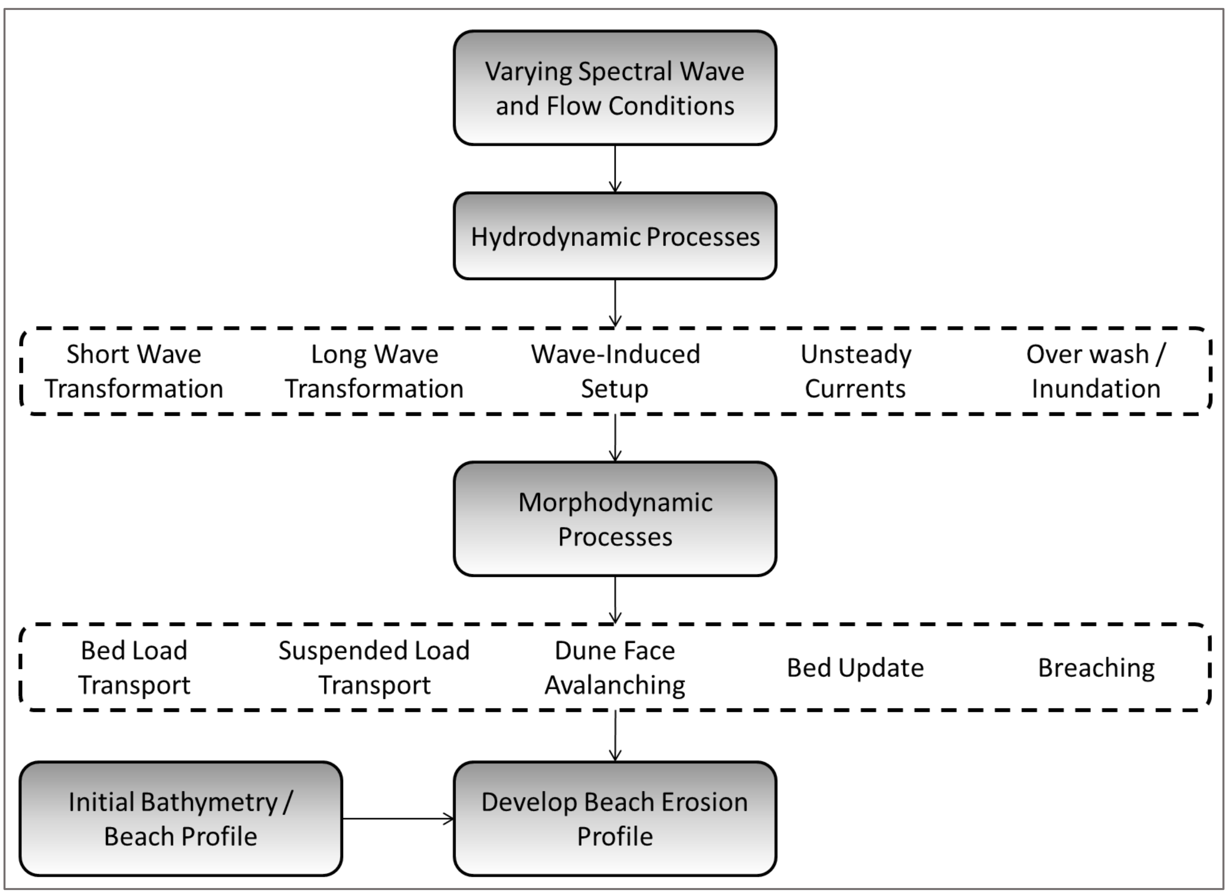


Figure 5-2: Rough outline of XBEACH Model Approach

Hydrostatics

The XBEACH model can either model in a hydrostatic or non-hydrostatic mode. The non-hydrostatic mode models short waves non-linearly and thus individually. The long waves are resolved based on the short wave propagation.

The main disadvantage of using the non-hydrostatic mode is that it is computationally expensive, since smaller time steps and higher spatial resolution is required. The advantages, however, include the capability of the model to include short wave run-up and over-washing that could have a significant impact on steep beach faces. Wave asymmetry and skewness are also resolved in this mode, contributing to a more accurate prediction of sediment transport.

The hydrostatic mode can be divided into either a stationary or instationary model. The stationary model neglects the effect of wave group variation and the accompanying long waves. Short waves are modelled by solving wave-averaged equations. This mode will typically be used to model cases where incoming waves are small with short periods, since long wave motion is not significant in these cases. An advantage of the stationary hydrostatic mode is that lateral boundaries remain undisturbed if longshore disturbance is uniform.

The instationary hydrostatic mode also solves short waves through wave-averaged equations, but the long waves associated with the incoming wave groups are also resolved. If the model has to run in hydrostatic mode for computational efficiency, it is necessary to use the instationary mode to model proper swash-zone processes.

Short Wave Action

The wave action balance is necessary to determine the wave forcing of short waves in shallow waters for the hydrostatic mode. The short wave action balance equation is given below:

$$\frac{\partial A}{\partial t}+\frac{\partial c_x A}{\partial x}+\frac{\partial c_y A}{\partial y}+\frac{\partial c_\theta A}{\partial \theta}=-\frac{D_W+D_F+D_V}{\sigma} \tag{4.5}$$

Where,

- A is the wave action and a function of the wave energy density and intrinsic wave frequency
- c_x, c_y are the wave action propagation speeds in the x- and y-direction and a function of the depth-averaged Langrarian velocities (cross-shore and alongshore) and group velocities
- c_θ is the wave action propagation speed in θ-space and takes bottom- and current refraction into account
- D_W is the total wave energy dissipation due to wave breaking distributed proportionally over the different wave directions
- D_F is the total wave energy dissipation due to bottom friction distributed proportionally over the different wave directions
- D_V is the total wave energy dissipation due to vegetation distributed proportionally over the different wave directions

The equations to calculate the separate terms in the wave action balance can be found in the XBEACH Manual. There are, however, different methods (listed in Table 5-4) through which the XBEACH model can solve the total wave energy dissipation due to wave breaking, depending on what the user requires.

Table 5-4: List of Methods to Solve Hydrostatic Wave Breaking Energy Dissipation

Wave Type	**Wave Breaking Formula**
Instationary	Roelvink (1993)
	Roelvink (1993) extended
	Daly *et al*. (2010)
Stationary	Baldock *et al*. (1998)
	Janssen & Battjes (2007)

Other factors that contribute to short wave motion and propagation that is included in the XBEACH model is wave shape, turbulence and the contribution of roller energy to radiation stress and wave energy. Although the short wave shape (skewness and asymmetry) is not modelled in the XBEACH model, non-linearity in the wave propagation is accounted for by applying one of two methods to determine wave shape. Either a formulation by Ruessink *et al*. (2012) may be selected, or a formulation by Van Thiel de Vries (2009). If the near-bed turbulence is bore averaged, the Ruessink *et al*. (2012) method is not applicable.

As mentioned, the near-bed turbulence that stirs the bed-sediment may be determined using a bore-averaged method. It may also be determined using a wave-averaged method.

Shallow Water Equations

Infra-gravity waves and flow caused by currents are modelled through shallow water equations. As part of the method to solve the long waves caused by wave groups and the return flow, the horizontal viscosity is required and determined using a method proposed by Smagorinsky (1963).

The effect of long waves and flow on bed shear stress is of great importance when the impact of long waves and flow on sediment transport has to be determined. One of the factors influencing the amount of bed shear stress is the dimensionless bed friction coefficient. Apart from the option to specify the coefficient based on laboratory data, XBEACH can calculate the bed friction coefficient through four other methods. Table 5-5 lists these methods as well as the important parameter used in each of the methods and typical values of these specific parameters.

Table 5-5: Methods Used to Determine Dimensionless Bed Friction Coefficient

Method	**Main Parameter**	**Typically Value**
Chezy	Chezy Coefficient	$55m^{1/2}/s$
Manning	Manning Number	$0.02s/m^{1/3}$
White-Colebrook	Nikuradse Geometrical Roughness	0.01-0.15m
White-Colebrook Grain Size	Sediment Diameter that 90% of the grains exceed	-

The energy of infra-gravity waves and return flow are dampened if vegetation occurs on the bottom. XBEACH can accommodate the effect of bottom vegetation on infra-gravity waves and return flow. Wind forcing also contributes to the propagation of long waves and may be included in the model of desired.

Sediment Transport

Sediment transport occurs because the sediment on the seabed is moved. In order for the sediment to move, it must often first be lifted of the seabed, because of turbulence. The lifted sediment contributes to the sediment concentration in the water column above the seabed. XBEACH models the sediment concentration in the water column using an advection-diffusion equation:

$$\frac{\partial hC}{\partial t} + \frac{\partial hCu^E}{\partial x} + \frac{\partial hCv^E}{\partial y} + \frac{\partial}{\partial x}\left[D_h h \frac{\partial C}{\partial x}\right] + \frac{\partial}{\partial y}\left[D_h h \frac{\partial C}{\partial y}\right] = -\frac{hC_{eq} - hC}{T_s} \qquad (4.6)$$

Where,

- C is the depth-averaged sediment concentration
- D_h is the sediment diffusion coefficient
- h is the water depth
- T_s is the adaption time for the sediment to respond to wave forcing
- C_{eq} is the equilibrium sediment concentration

The calculations for the above-mentioned terms are given in the XBEACH Manual. If the suspended sediment concentration is higher than the equilibrium sediment concentration, deposition of sediment will take place and *vice versa.* XBEACH can solve the sediment transport using one of two methods to determine the equilibrium sediment concentration. The first option is to calculate the sediment concentration using the Soulsby-Van Rijn method (Soulsby, 1997; Van Rijn, 1984). The alternative is to use the van Thiel-Van Rijn method (Van Rijn, 2007; van Thiel de Vries, 2009).

It is known that bed slope affects the sediment transport, but XBEACH does not incorporate this effect in modelling hydrodynamics. There are, however, factors that can be applied to change the magnitude of sediment transport based on the slope.

Bottom Updating

Bed updating is the process through which the bed level is updated due to the modelled sediment transport regime. The bed level changes is based on sediment flux, slope avalanching and bed composition.

Verification of Model

The XBEACH model has been validated for storm impacts on dunes and urbanised coasts as well as for some dissipative and reflective beaches in Europe as part of the model formulation (Deltares, 2015). Corbella & Stretch (2012) evaluated the accuracy of SBEACH and XBEACH in predicting cross-shore erosion and concluded that XBEACH provides predictions that are generally more accurate than SBEACH.

Marr (2015) assessed the accuracy of XBEACH to predict cross-shore beach profile evolution under erosive bichromatic wave conditions. Flume experiments were modelled using XBEACH and it was found that XBEACH did not seem to accurately predict the cross-shore beach profile response under wave grouping conditions (Marr, 2015). McCall (2008) concluded that XBEACH over predicts the morphological response of the cross-shore beach profile in shallow water. Daly (2009) confirmed McCall's (2008) findings after he studied the accuracy of XBEACH to predict beach profile response under low-frequency waves.

Under conditions of tidal variation, Williams *et al.* (2012) concluded that the cross-shore beach profile response in the inter-tidal region is under-estimated. Williams *et al.* (2012) also found that XBEACH did not model distinct berms in cases where berms were observed in the field studies. This observation was attributed to the poor simulation of wave uprush and backwash by XBEACH.

Pender & Karunarathna (2013) found that XBEACH predicts both erosion under storm conditions and accretion during recovery periods relatively well based on Narrabeen Beach field data. This indicates that XBEACH can predict beach profile response over longer periods.

5.2.3 DUNERULE

As mentioned, the DUNERULE model is a simplified version of the process-based CROSMOR2007 model. The CROSMOR2007 model models the propagation and transformation of individual incoming waves using a probabilistic model. It is possible to model long waves using the CROSMORE2007 model. The sediment transport is based on the impacts of waves and currents.

Van Rijn (2008) extensively validated the CROSMOR2007 model after which he derived the simplified DUNERULE model. Van Rijn used a Dutch reference case to model the dune erosion of a standard storm over five hours with a storm surge level of 5m above mean sea level. Based on the results of this sensitivity study, Van Rijn derived the following formula to determine the volume of dune erosion after five hours of storm impact, known as the DUNERULE model (Van Rijn, 2008):

$$V_{d,t=5} = 170m^3/m\left(\frac{0.000225m}{d_{50}}\right)^{\alpha_1}\left(\frac{S}{5m}\right)^{\alpha_2}\left(\frac{H_{S,0}}{7.6m}\right)^{\alpha_3}\left(\frac{T_p}{12s}\right)^{\alpha_4}\left(\frac{\tan\beta}{0.0222}\right)^{\alpha_5}\left(1+\frac{\theta_0}{100}\right)^{\alpha_6} \quad (4.7)$$

Where,

- $V_{d,t=5}$ is the volume of dune erosion over five hours (m^3/m)
- d_{50} is the median grain size of the dune sediment (m)
- S is the storm surge level above mean sea level including the effect of tides and wave set-up (m)
- $H_{S,0}$ is the offshore significant wave height (m)
- T_p is the peak wave period (s)
- $\tan\beta$ is the slope between the -3m depth contour (below mean sea level) and the dune toe
- θ_0 is the offshore wave incidence angle to coast normal (°)
- α_1 = 1.3, α_2 = 1.3 ($S<S_{ref}$) and α_2 = 0.5 ($S>S_{ref}$), $\alpha_3 = \alpha_4 = \alpha_6$ = 0.5, α_5 = 0.3

From the equation above, the mean dune recession over five hours of storm impact is determined. If the storm duration is less or more than five hours, the erosional volume is calculated by multiplying the five hour volume with one of the following factors:

$$(\frac{t}{5h})^{0.5}, for\ t > 5h \quad (4.8)$$

$$(\frac{t}{5h})^{0.2}, for\ t < 5h \quad (4.9)$$

The dune recession is also indicative of the shoreline recession. The maximum dune and thus shoreline recession at the storm surge level is estimated as 1.5 times the mean dune recession.

$$R_d = \frac{V_{d,t=5}}{S+B} \quad (4.10)$$

Where,

- R_d is the mean dune recession (m)
- B is the dune height above mean sea level (m)

It should be noted that DUNERULE only models erosional cases above the storm surge level. In other words, DUNERULE cannot predict beach profile response below the water level and the water level must be above the mean sea level in order to obtain any results. Furthermore, a constant water level must be specified and appropriate methods to incorporate water level variation have not been provided.

After Van Rijn (2008) verified the DUNERULE model, he concluded that DUNERULE is also more accurate for larger storms, but could still be used to predict beach profile response of smaller storms. Since the CROSMOR2007 model has the capability of including the effect of long waves on beach profile response prediction, it is assumed that the effect of long waves was included in the reference case from which the DUNERULE model was derived. The impact of long waves cannot specifically be extracted from the model and no input can be provided to specify long waves individually. Few additional studies by other authors than Van Rijn have been done to validate the DUNERULE model.

5.3 Model Installation & General Set-up

5.3.1 SBEACH

SBEACH 3.0 was used to run the SBEACH numerical model. In order to access the user interface of SBEACH 3.0, a DOS emulator had to be installed. DOSBox 0.74 was downloaded and installed as the DOS emulator. The SBEACH user interface (opening screen shown in Figure 5-3) was run through DOSBox.

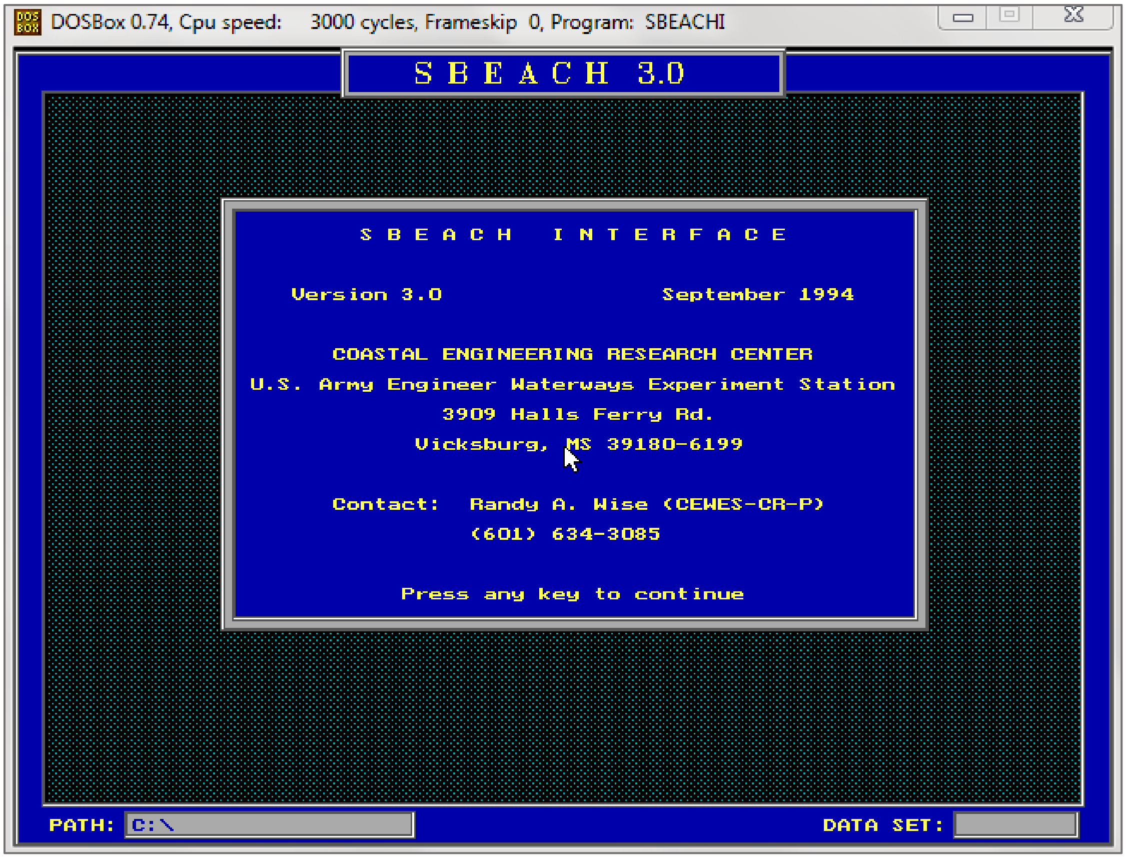


Figure 5-3: SBEACH User Interface as run through DOSBox

A complete SBEACH Manual (Rosati *et al*., 1993) is available. This section will, however, cover the basics of setting up the SBEACH numerical model. In order import all the necessary information to run the model, a configuration file (.cfg) must exist in the SBEACH directory. The information that has to be entered into the configuration file is summarized in Table 5-6. The table also indicates which additional files are necessary to define the initial and measured beach profiles, wave height, period and angle, wind speed and direction and water elevation levels.

Table 5-6: SBEACH Configuration File Set-up

Input	Description
Run Title	The title of the model run as determined by self must be given.
Input Units	Input units must be entered as either American or SI units. In this study, SI units were used.
Grid Set-up	The grid set-up includes defining the landward boundary of the initial beach profile as well as the number of cells (maximum 1000) in the grid. The grid may be set up with constant cell widths or variable cell widths divided over different regions defined from the landward to the seaward boundary.
Time Step Set-up	The amount of time steps in the model run must be defined as well as the length of a time step in minutes. Time steps where intermediate outputs are wanted may also be entered.
Profile Comparison	It must be indicated if a measured profile exists either for comparison or calibration purposes. If a measured profile exists, it must be provided in a .PRM file. Additional points where difference in profile depths are wanted may also be defined.
Calibration Coefficients	The transport rate coefficient (m^4/N) is the main calibration parameter. The default value is 1.75E-6 m^4/N and may be adjusted to any value in the range of 0.5E-6 to 2.5E-6 m^4/N.
	The coefficient for the slope dependent term (m^2/s) may be adjusted in order to calibrate the model. It is recommended to use the default value of 0.002 m^2/s, but it may be adjusted to any value in the range of 0.001 to 0.003 m^2/s.
	It is advised to use the default transport rate decay coefficient multiplier (0.5). It may be defined as a value between 0.1 and 0.5 if fine tuning is required. The larger the multiplier, the larger the sediment decay rate to the breaking point.
Water Temperature	The water temperature must be defined in degrees Celsius.

Input	**Description**
Wave Input	Monochromatic or irregular wave types must be entered. If monochromatic waves are modelled, the constant wave height and period must be supplied. If irregular waves are modelled, irregular wave time series (significant wave height and peak wave period) must be supplied in a .WAV file. The time step between consecutive wave readings must be defined. The wave angle must be defined in a similar manner as the wave height and period. The input must either be constant or variable. Variable angle data must be supplied in a .ANG file and the corresponding time step must be defined. If deep water waves are provided, the wave input water depth must be defined as 0. If the input waves, however, originate at a specific depth, this depth must be provided. Randomisation of wave height may be selected. Without randomisation, the wave heights between defined time steps are calculated through linear interpolation. Randomisation of the wave heights will result in a more realistic continuous wave height time series.
Water Elevation Input	Water elevation must be defined as either constant or variable. If constant, the constant water elevation must be defined. Variable water levels must be supplied in a .ELV file and the time step must be provided.
Wind Input	Wind speed and angle must be defined as either constant or variable. If constant, the constant wind speed and angle must be defined. Variable wind speed and angles must be supplied in a .WND file and the time step must be provided.
Beach Profile and Sediment Properties	Initial beach profiles must be supplied in a .PRI file. The depth where the swash zone begins, must be defined as a depth between 0.15 and 0.5m (a default value of 0.3m is recommended). The effective median grain size diameter (d_{50}) must also be provided along with the maximum slope (between 15 and 90°) before avalanching occurs. The default maximum slope is set at 30°, but can be adjusted to calibrate the model.

After an SBEACH model is run, different outputs may be requested. The outputs include graphs of the modelled beach profile and intermediate beach profiles (Figure 5-4a) and the volume change rate (Figure 5-4b) along graphs of the maximum wave heights (Figure 5-4c), water depths (Figure 5-4d) and water elevations (Figure 5-4e) during the time series. Wave heights (Figure 5-4f) and water elevations (Figure 5-4g) at intermediate time steps may also be requested. Furthermore, a graph representing the wave height, wave period and water elevation time series (Figure 5-4h) are also generated. The images provided in Figure 5-4 are outputs of the SBEACH example run EX_2A as provided with the download of SBEACH.

The final and intermediate beach profiles are also provided in a .PRC file from where the data can be copied for analysis purposes. The data of waves, water level and winds as it varied across the profile at the intermediate time steps are available in a .XVR file. Other results from the model run are available in a .RPT file and include a summary of calculated parameters such as the difference between the final and initial beach profiles as well as the difference between final modelled and measured profiles.

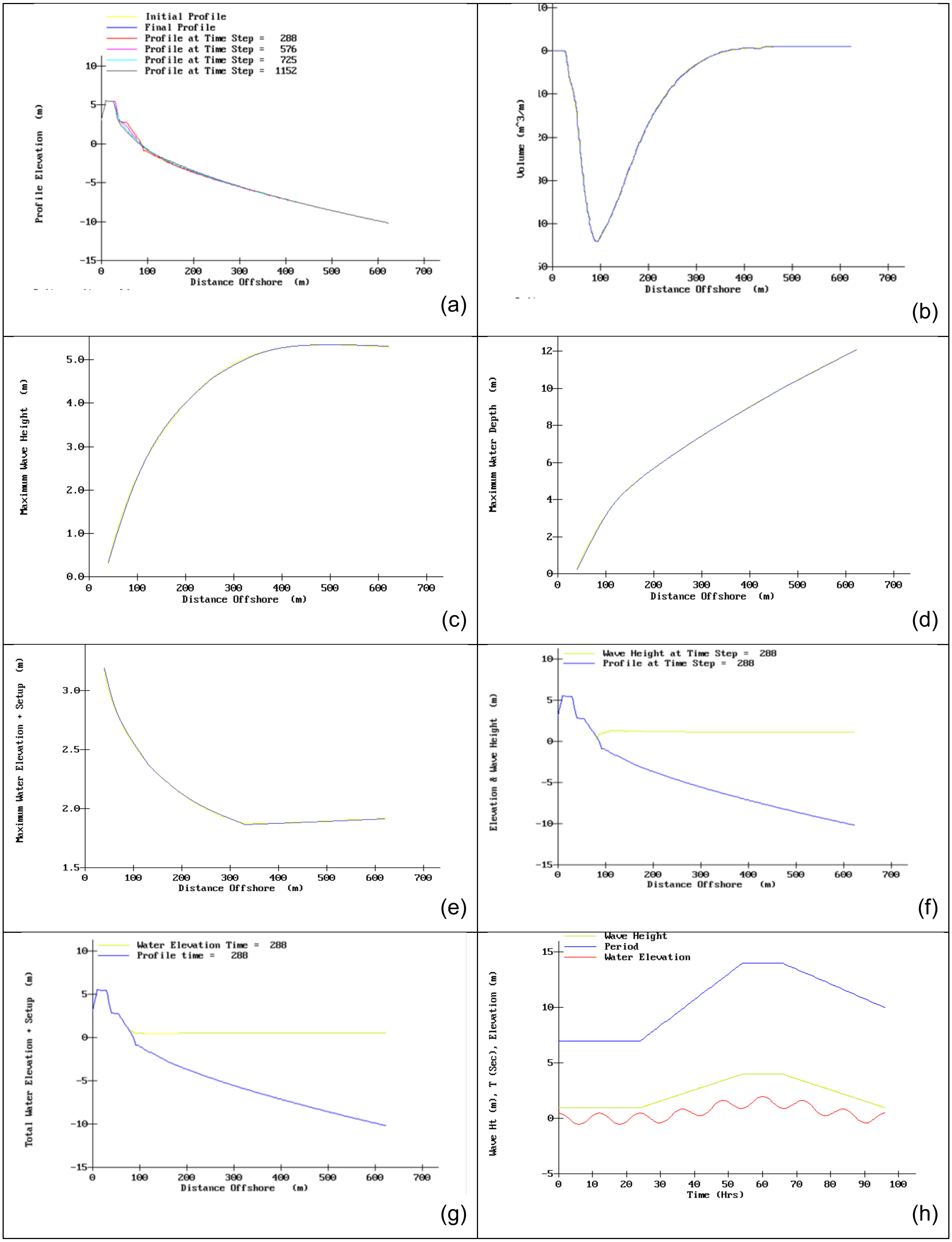


Figure 5-4: Graph Output of SBEACH Numerical Model

5.3.2 XBEACH

XBEACH V1.22.4867 was downloaded from the open-source Deltares website. This version of XBEACH includes a precompiled netCDF executable, enabling XBEACH to support a netCDF output. In order to obtain visual results from the XBEACH model, Quickplot was downloaded as part of the Delft3D package. A user license had to be obtained in order to download the Delft3D package and thus the Quickplot output utility.

XBEACH runs were executed by running the xbeach.exe application. Once the model runs were finished, the xboutput.nc files were opened using Quickplot. Quickplot provided profiles of the water level, waves and cross-shore at different time steps as requested by the user.

In order for XBEACH to run, a params.txt file must be available. In the params.txt file, the user input for the XBEACH model is provided. The input consists of specified values, names of input files and desired methods to solve the numerical model. The XBEACH Manual (Deltares, 2015) describes the input parameters in detail. Table 5-7 summarises the main input parameters that are required.

Table 5-7: XBEACH Input Parameters Summary

Input Boundary Conditions	**Description**
Physical Processes	It is not necessary to specify whether each possible process is turned on or off. On default, short waves, sediment transport, long waves, flow, morphology and avalanching processes are turned on. If some of these processes are not required, they can be turned off. Other processes which may be turned on include the non-hydrostatic model, ground water flow, ship motions and vegetation. Processes are turned on by setting them equal to 1 and they are turned off by setting them equal to 0.

<table>
<tr><th>Input Boundary Conditions</th><th>Description</th></tr>
<tr><td>Grid and Bathymetry</td><td>Grids can be set up either in fast 1D, 1D or 2DH. The x-direction in the grid set-up refers to the cross-shore axis, whereas the y-direction refers to the longshore axis. This study only focused on 1D cross-shore modelling (fast 1D) and therefore the amount of grid cells in the y-direction (ny) was always set as zero. The grid cells in the x-direction may be set up using grid cells with constant size by setting the dx value equal to the preferred grid cell size. Grid cells in the x-direction may also be set up with varying size. In this case the x-coordinates of grid points are given in a .grd file.

The cross-shore initial profile must be provided in a .dep file. This file contains the depths at the grid point x-coordinates. Other data that may be provided includes the grid orientation and directional limits for short waves.</td></tr>
<tr><td rowspan="3">Wave</td><td>Spectral wave conditions can be selected for the model. Spectral wave conditions include JONSWAP, Swan and Vardens spectral conditions to generate wave groups. It is also possible to select the JONSWAP table option that allows the modelling of a sequence of time varying wave groups.</td></tr>
<tr><td>Non-spectral wave boundary condition options include stationary wave sea state wave conditions, or first- or second-order wave time series.</td></tr>
<tr><td>Special wave boundary conditions may also be selected, such as the option to reuse previous wave conditions or not have any waves. Another special boundary is the bi-chromatic wave conditions. In this case monochromatic waves are defined along with an accompanying long wave period. XBEACH then combines this data to generate short-wave envelopes and a bound long wave.</td></tr>
</table>

Input Boundary Conditions	**Description**
Flow	Flow boundary conditions have to be specified for the offshore, land and lateral boundaries of the model. 1D or 2D weakly reflective boundaries may be set up at the offshore (front) and land (back) boundary. Other options include a wall or water level boundary. The lateral boundaries may also be specified as a wall, but by default, it is defined as a Neumann boundary with a constant water level gradient. As part of the flow conditions, free long waves may also be defined.
Tide	Tidal time series may be incorporated. In this case it should be specified at which boundary points the tides are applicable. It is possible to neglect tidal variation with time and just specify a constant water level.
Wind	Wind data may be added to the model.
Sediment	Physical sediment properties that should be defined, if known, are the $d_{15,50,90}$ sediment grain sizes as well as the porosity of the sediment and the solid sediment density. Sediment calibration parameters that may be adjusted for calibration purposes include the sediment transport and critical velocity calibration coefficients. If different sediment classes exist, they should be indicated.

More advanced input parameters are also required if the default values are not sufficient. The list of these parameters are extensive and thus not discussed in this study. Physical constants that should, however, be specified are the gravitational acceleration and the density of the water.

The output variables must be specified in the params.txt file. Most importantly, the model time span (tsart and tstop) must be specified in seconds, as well as the intermediate output time intervals. In order for Quickplot to read the results, the output must be in a netcdf format. Global output variables must also be defined. The list is extensive, but include wave heights, water level, bed level, fraction of breaking waves, orbital and Generalized Lagrangian Mean (GLM) velocities and incoming bound long waves.

After an XBEACH model is run, a xboutput.nc file is generated. This file is opened in Quickplot. The user can define the variables that Quickplot should plot, for example: initial, intermediate and final bed profiles as well as water elevation and waves. An example of a Quickplot output is given in Figure 5-5. The results can be extracted to a Matlab file.

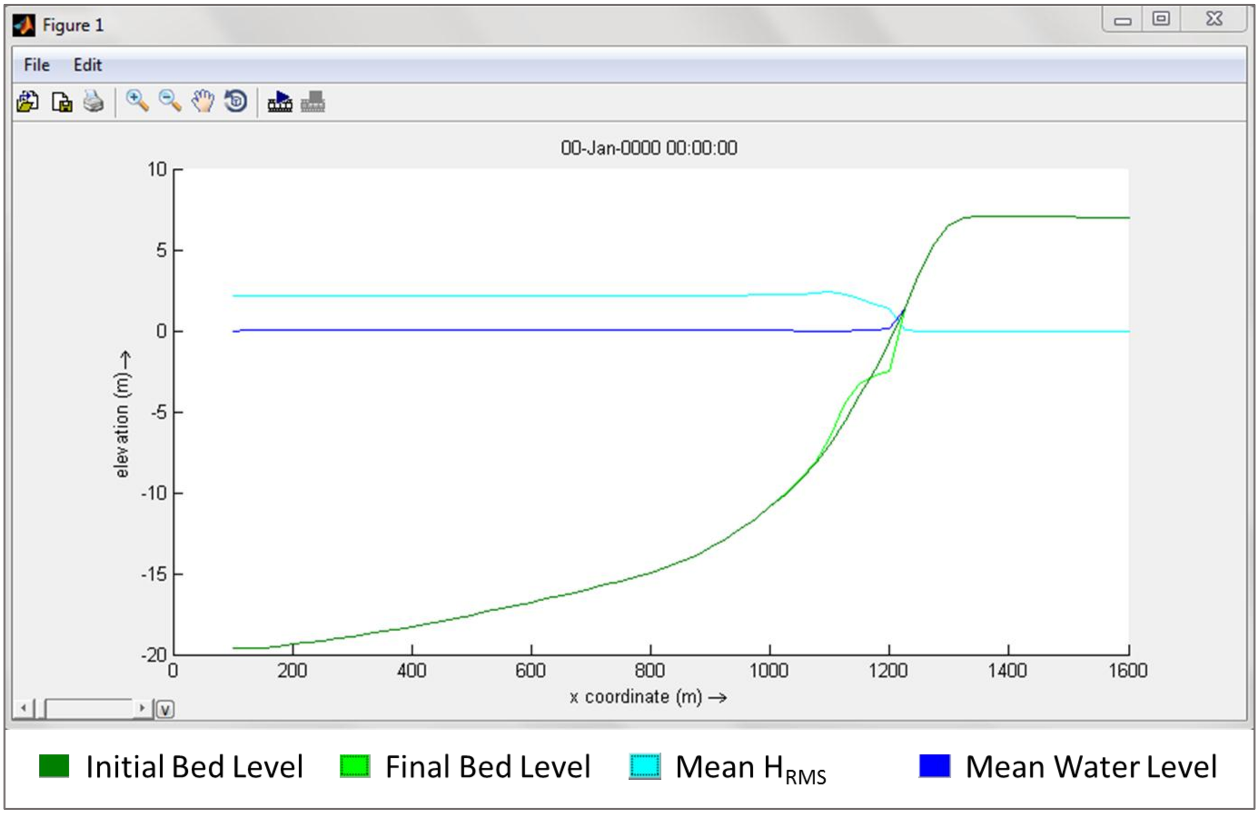
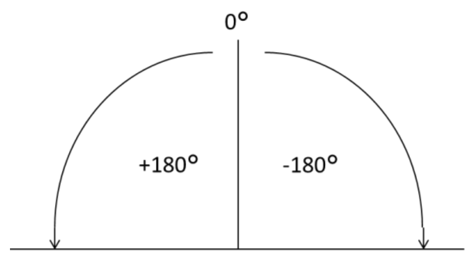


Figure 5-5: Example of XBEACH output using Quickplot

5.3.3 DUNERULE

Since DUNERULE is a simple model, it is available in an Excel file provided by Van Rijn (2008). The input values are tabulated in Table 5-8.

Table 5-8: Summary of Input Parameters for DUNERULE

Input Parameter	**Measurement Unit**	**Description**
Median Grain Size (d_{50})	m	-
Storm Surge Level (S)	m	Storm surge level above Mean Sea Level, including Tidal Level and Wave Set-up
Offshore Significant Wave Height ($H_{s,0}$)	m	-
Peak Wave Period (T_p)	s	
Beach Slope (tanβ)	m/m	Slope of beach between -3m depth contour and dune toe (+3m contour)
Offshore Wave Angle (θ_0)	°	

DUNERULE does not require an input beach profile nor does it provide a final beach profile. It does, however, provide sediment erosion volumes per unit width, as well as the average and maximum dune retreat in meters.

5.4 Model Set-up to Determine Sensitivity of Models to Changing Parameters

5.4.1 General Constant Parameters

5.4.1.1 Initial Cross-Shore Beach Profile

In all the model sensitivity tests, the same initial beach profile was used. The initial beach profile was set up as a planar beach face with a slope of 1:20. A planar beach slope was selected, since the purpose of this part of the study was merely to analyse the model sensitivity and not to specifically determine how beach profiles develop. If a planar beach profile indicated sensitivity based on the dependent variables, then any other beach profile would probably also be sensitive to the studied parameter (water level or storm duration). The depth of the profile extended to 30m beneath mean sea level and the dune height (or height of profile) reached 20m above mean sea level. The depth and height of the beach profile were chosen to ensure that all the significant sediment transport occurs between these two boundaries. Figure 5-6 illustrates the initial beach profile that was used in all of the model sensitivity runs.

In both SBEACH and XBEACH (models requiring initial profile input) a one dimensional grid was set up with constant grid cells widths (1.5m), spread along the beach profile from -550m landward of the mean sea level to 600m offshore.

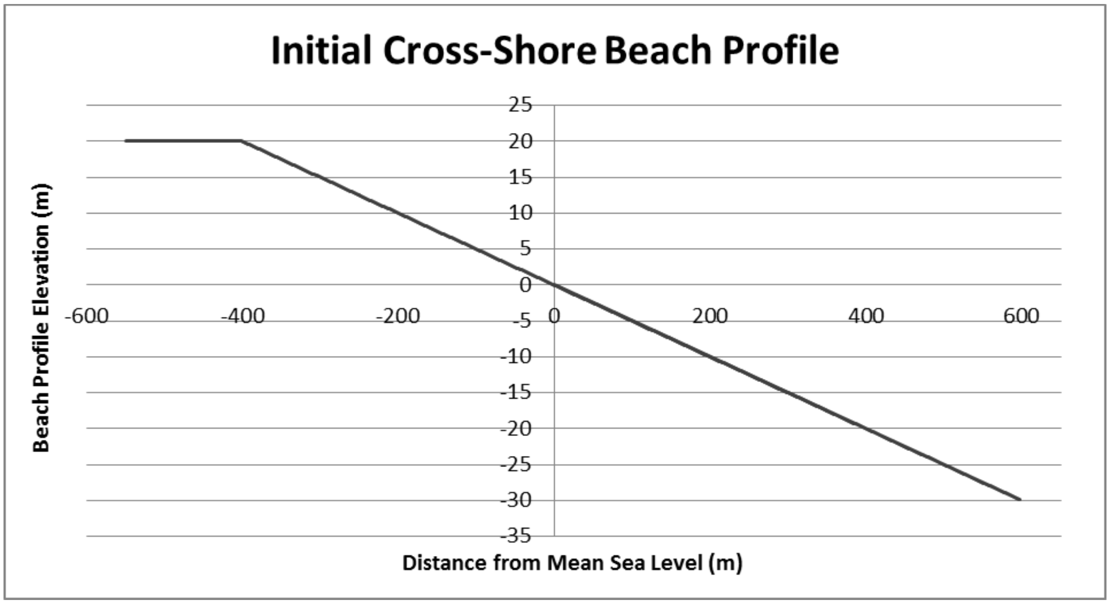


Figure 5-6: Initial Cross-Shore Beach Profile for Model Sensitivity Runs

5.4.1.2 Wave Conditions

It was initially intended to do sensitivity runs for both erosive and accretive conditions. DUNERULE cannot, however, model accretive conditions at all. Although SBEACH is theoretically able to model accretive conditions, no wave conditions were found that caused accretion of the initial profile in SBEACH. The sensitivity analyses were thus done using three random offshore wave conditions with different severities: calm, moderate and rough based on the information in Section 2.7. The monochromatic wave conditions that applied for these three wave condition cases are tabulated in Table 5-9.

Table 5-9: Set Wave Conditions for Sensitivity Tests

Parameter	**Case 1**	**Case 2**	**Case 3**
Significant Wave Height	0.8m	3m	6m
Peak Wave Period	6s	12s	16s

5.4.1.3 Sediment and Physical Properties

The constant sediment properties were chosen based on typical fine to medium grained sand properties as discussed in Section 2.5. The median sand diameter was chosen as 0.25mm. The porosity of beach sand typically varies between 25 and 50 percent (Argonne National Library, 2016). A porosity of 35% was applied to all the sensitivity cases. The density of a sand particle that is quartz-based is about 2 650kg/m^3 (Section 2.5.2) and was used as the density for the sand in these model runs. The gravitational acceleration and density of the sea water is often required in the model set-ups and were set to 9.81m/s^2 and 1 025kg/m^3 respectively. The temperature of the sea was taken as 20°C for all cases, since XBEACH assumes a constant temperature of 20°C for its calculations.

5.4.1.4 Time Steps & Calibration Parameters

SBEACH requires a time step input. For the sea level variation and storm duration model runs, the time steps were always defined as one minute. The long wave model runs required shorter time steps as discussed in Section 5.4.4. XBEACH has an automatic time step based on the Courant criterion (Deltares, 2015), but intermediate output time steps may be specified by the user. The calibration parameters and other parameters that have default settings were kept at their default values in both SBEACH and XBEACH when the model sensitivity runs were done.

5.4.2 Sea Level Variation

Sea level variation is caused by tides, wave set-up and storm surge. Most numerical models include wave set-up in their prediction of cross-shore sediment transport. Storm surge and tide must, however, be added manually. The highest recorded storm surge was observed in Australia in 1899. According to observations the storm surge level (which included the effect of tides) was more or less 14m (Wunderground, 2016) to mean sea level. There is, however, doubt on whether this record is accurate. Other record holding storm surges vary between 8m and 12m. The largest tidal difference in the world (16.3m) occurs in the Bay of Fundi. This tidal difference could lead to a -8m low tide to mean sea level.

XBEACH cannot model above a water elevation level above 5m to mean sea level and it was thus decided to model a water level variation range of -5m to +5m to mean sea level in the sensitivity analysis. All the water levels were modelled with the same initial cross-shore beach profile and for all three wave conditions (Case 1-3) over a set period of 12 hours. Table 5-10 provides a list of the model runs and their modelled water levels.

Table 5-10: Water Level Elevations to Mean Sea Level for Sensitivity Analysis Runs of Water Level Variation in Different Cross-Shore Sediment Transport Numerical Models

Run	Water Level to MSL (m)
1.1, 2.1, 3.1	+5
1.2, 2.2, 3.2	+4
1.3, 2.3, 3.3	+3
1.4, 2.4, 3.4	+2
1.5, 2.5, 3.5	+1
1.6, 2.6, 3.6	0
1.7, 2.7, 3.7	-1
1.8, 2.8, 3.8	-2
1.9, 2.9, 3.9	-3
1.10, 2.10, 3.10	-4
1.11, 2.11, 3.11	-5

The model runs were numbered in the format “Run a.b”, where “a” is the wave case and “b” is the water level case. Eleven runs were done for each of the three wave cases in all three models. In total 33 runs (Run 1.1 to Run 3.11) were completed for each model. The wave conditions and water levels for all 33 runs are provided in Appendix A-1. The different sea level variation cases were modelled in XBEACH, SBEACH and DUNERULE. The configuration set-up for Run 1.1 in all three models are available in Appendix A-2.

5.4.3 Storm Duration

For this study the effect of storm duration was determined by modelling storms with a constant significant wave height and peak wave period over different storm durations. From the three wave conditions that are listed in Section 5.4.1, only Case 2 and 3 were selected to determine the effect of storm duration on beach profiles in different numerical models. Case 1 was not selected, since it was not representative of storm conditions. Case 2 was chosen in order to represent a mild storm (the storm surge level was set at +2m to mean sea level) and Case 3 as an extreme storm (the storm surge level was set at +4m to mean sea level).

The modelled storm durations varied between 12 and 96 hours. Apart from DUNERULE, where one Excel spreadsheet is used to model the different cases, SBEACH and XBEACH were purely run for the longest duration (96 hours) and the intermediate output profiles were subsequently analysed to determine the effect of shorter durations. In XBEACH, output may be requested at any given time, but for SBEACH a maximum of 10 intermediate outputs may be requested. Therefore, two SBEACH models had to be run in order to obtain results for all 15 storm durations. The model runs and corresponding storm durations at which the intermediate beach profiles were studied are listed in Table 5-11.

Table 5-11: Model Runs and Storm Durations for Sensitivity Analysis of Storm Duration Variation in Different Cross-Shore Sediment Transport Numerical Models

Run	Duration (h)
1.1, 2.1, 3.1	12
1.2, 2.2, 3.2	18
1.3, 2.3, 4.3	24
1.4, 2.4, 3.4	30
1.5, 2.5, 3.5	36
1.6, 2.6, 3.6	42
1.7, 2.7, 3.7	48
1.8, 2.8, 3.8	54
1.9, 2.9, 3.9	60
1.10, 2.10, 3.10	66
1.11, 2.11, 3.11	72
1.12, 2.12, 3.12	78
1.13, 2.13, 3.13	84
1.14, 2.14, 3.14	90
1.15, 2.15, 3.15	96

The model cases were numbered in the format “Run a.b”, where “a” is the wave condition and “b” is the storm duration case. For SBEACH two model runs were done for both of the storm wave conditions. The first model provided profiles for storm duration Cases 1 to 8 and the second model provided to storm duration Cases 9 to 15. XBEACH required one model run for each of the storm conditions. The model runs had a total duration of 96 hours and the intermediate profiles at the specified durations were analysed. In DUNERULE each case was modelled separately. In total 30 cases (Run 2.1 to Run 3.15) were analysed for each model. The storm wave conditions and durations for all 30 runs are provided in Appendix B-1. The configuration set-up for Run 2.1 in all three models are available in Appendix B-2.

5.4.4 Long Waves

For this study, the effect of free long waves was determined by modelling three different monochromatic wave conditions (listed in Table 5.9) and comparing the model response to the model response obtained by monochromatic and free long wave impact. The initial beach profiles were the same for all the model runs as described in Section 5.4.1.1. The final profiles were those obtained by the numerical models after 4-hour impact of the specific wave conditions. For each monochromatic wave condition, three different free long wave periods were used.

Although the XBEACH model is set up to solve for long waves, the model does not provide the opportunity to specify free long wave input separately. Since neither SBEACH nor XBEACH can model free long waves, the long waves were modelled as water level variation by identifying the wave height in 2.5-second time steps over a 4-hour period. Although this method is not truly representative of free long waves, this approach was the best solution to at least try to comprehend the effect of free long waves on beach profile response. The effects of free long waves, such as wave run-up and wave set-up, were neglected through this approach and essentially, only the effect of the very small but frequent water level variation caused by free long waves was assessed. DUNERULE is not capable of modelling the proposed water level variations and was excluded from this sensitivity study. The long waves were modelled with sinusoidal shapes. Figure 5-7 illustrates an example of how data points were entered to simulate a long wave with a 30 second period and 0.1m wave height as water level variation in both SBEACH and XBEACH.

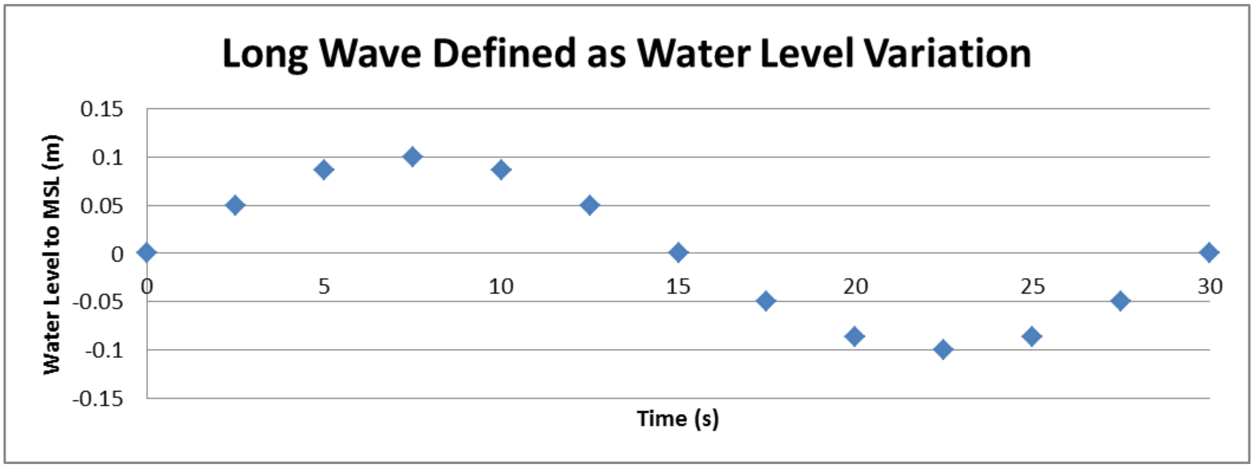


Figure 5-7: Example of Representation of a Long Wave in SBEACH and XBEACH as Water Level Variation

Four model runs were done for each wave condition. One of the four runs was to establish the beach profile response to monochromatic wave impact only. The other three runs were done with the same monochromatic wave conditions, but with added free long waves with different wave periods. As discussed in Section 2.6.4.1, infra-gravity waves typically have periods of 30s to 200s. The three different wave periods were selected as 30s, 110s and 200s in order to be representative of typical long wave periods. The duration of impact was 4 hours for all the model runs. The same time step used in the other sensitivity studies was not used. The SBEACH time step was specified as 2.5s, corresponding to the water elevation input time steps. This way a more accurate water level fluctuation was obtained. Table 5-12 provides the monochromatic and long wave input for each model run that was done to determine the sensitivity of the models to free long waves. The runs were named in the format ‘Run F.x.y’, where ‘F’ indicates the run is for free long waves, ‘x’ indicates the monochromatic wave conditions and ‘y’ indicates the long wave condition.

Only XBEACH is capable of modelling bound long waves generated as a result of bichromatic wave conditions and therefore only the sensitivity of XBEACH to bound long waves was analysed. In XBEACH, bichromatic waves are specified by defining the short wave root-mean-square wave height, representative period and a bound long wave period to govern the short wave envelope formation.

Table 5-12: Model Runs to Determine Model Sensitivity to Free Long Waves

Run	Monochromatic Short Waves		Free Long Waves	
	Height (m)	Period (s)	Height (m)	Period (s)
F.1.1	0.8	6	-	-
F.1.2	0.8	6	0.08	30
F.1.3	0.8	6	0.08	110
F.1.4	0.8	6	0.08	200
F.2.1	3	12	-	-
F.2.2	3	12	0.3	30
F.2.3	3	12	0.3	110
F.2.4	3	12	0.3	200
F.3.1	6	16	-	-
F.3.2	6	16	0.6	30
F.3.3	6	16	0.6	110
F.3.4	6	16	0.6	200

Each of the three monochromatic wave conditions listed in Table 5-9 were used as the short wave input. Under each short wave condition, three different bound long wave periods were modelled. The initial beach profiles were the same for all the model runs as described in Section 5.4.1.1. The final profiles were those obtained by the numerical models after 4-hour impact of the specific wave conditions. Table 5-13 provides the short wave and bound long wave input for each model run that was done to determine the sensitivity of the models to bound long waves. The runs were named in the format 'Run B.x.y', where 'B' indicates the run is for bound long waves, 'x' indicates the short wave conditions and 'y' indicates the long wave condition.

Table 5-13: Model Runs to Determine Model Sensitivity to Bound Long Waves

Run	Monochromatic Short Waves		Bound Long Waves
	Height (m)	Period (s)	Period (s)
B.1.1	0.8	6	-
B.1.2	0.8	6	30
B.1.3	0.8	6	110
B.1.4	0.8	6	200
B.2.1	3	12	-
B.2.2	3	12	30
B.2.3	3	12	110
B.2.4	3	12	200
B.3.1	6	16	-
B.3.2	6	16	30
B.3.3	6	16	110
B.3.4	6	16	200

The input short and long wave conditions and durations for all 24 runs are provided in Appendix C-1. The configuration set-up for Run F1.2 for SBEACH and XBEACH are available in Appendix C-2A. The bound long wave set-up for XBEACH is provided for Run B.1.2 in Appendix C-2B.

5.5 Model Set-up to Assess the Accuracy of Model Prediction

5.5.1 Sea Level Variation

5.5.1.1 Model Calibration

The SBEACH and XBEACH models were calibrated for Case 911 (discussed in Section 4.2) by modelling the cross-shore beach profile response over 6.2 hours and 15.5 hours and adjusting the calibration parameters until the modelled beach profile responses were most representative of the actual measured beach profile responses.

The calibration parameters were adjusted in such a way that the best Brier Skill Score (discussed in Section 7.1.1) and volumetric fit (volume eroded above the water level) to the measured data were obtained. When a big difference existed between the 6.2-hour and 15.5-hour calibration results, calibration factors were selected based on the 15.5-hour profile results. More focus was put on a good volumetric fit than a good Brier Skill Score fit.

In all three numerical models the waves were modelled as monochromatic waves approaching the beach perpendicularly. The grid spacing for the SBEACH and XBEACH numerical models were kept the same as the spacing at which the actual profile measurements were made (horizontal spacing of 1.2m). Since the calibration process was merely used to determine the values of the calibration parameters and not to assess the accuracy of the models, a time step of one minute was used in SBEACH and a morphological acceleration factor of 10 was applied to the XBEACH model. The water levels were specified at one-minute intervals.

The numerical model, SBEACH, was calibrated in the development phase based on some of the CERC Large Wave Tank experiments (Larson & Kraus, 1989). It was therefore not necessary to adjust the default calibration parameters. However, the SBEACH model was still calibrated for the specific cases in this study, since the overall calibration by Larson & Kraus (1989) was based on average calibration values between different cases and calibration could essentially yield results that are more accurate. Table 5-14 lists the parameters that were calibrated for SBEACH, the range of values that the calibration parameters may be, the specific calibration values that were tested and the final calibrated values. The results of the SBEACH calibration runs for both calibration profiles in all five cases are provided in Appendix D-1.

Table 5-14: SBEACH Calibration Parameters for Case 911 (Water Level Variation Assessment)

Calibration Parameter	Range	Default	Values Tested
Transport Rate Coefficient (m^4/N)	0.5-2.5	1.75	0.50, 1.15*, 1.75, 2.00, 2.50
Coefficient for Slope Dependent Term (m^2/s)	0.001-0.003	0.002	0.001*, 0.0015, 0.002, 0.0025, 0.003
Transport Rate Decay Coefficient Multiplier	0.1-0.5	0.5	0.1, 0.2, 0.3, 0.4, 0.5*
Depth Corresponding to Landward End of Surf Zone (m)	0.15-0.5	0.3	0.15*, 0.3, 0.4, 0.5
Maximum Slope Before Avalanching (°)	15+	30	15, 30*, 45

***Final calibrated value**

The same calibration approach was used for XBEACH as was used for SBEACH, but with different calibration parameters. There are numerous factors that can be adjusted in XBEACH in order to obtain more accurate results. It is, however, not time efficient to calibrate all these parameters and therefore only four parameters were selected to be calibrated. Studies done by Pender & Karunarathna (2012), Vousdouskas *et al*. (2012), Riesenkamp (2011) and Deltares (2015) indicated that the following four parameters are the most important to be calibrated for model runs without the effect of long waves:

- wetslp: Critical avalanching slope under water
- gamma: Breaker parameter
- facua: wave asymmetry and skewness factor
- fw: bed friction factor

The *morfac* parameter in XBEACH was adjusted to accelerate the erosion and deposition process in XBEACH. This factor leads to slightly less accurate results, but is more time efficient and thus acceptable for the calibration process. The results of the XBEACH calibration runs for both calibration profiles in all five cases are provided in Appendix D-2. Table 5-15 lists the parameters that were calibrated for XBEACH, the range of values that the calibration parameters may be, the specific calibration values that were tested and the final calibrated values.

Table 5-15: XBEACH Calibration Parameters for Case 911 (Water Level Variation Assessment)

Calibration Parameter	Range	Default	Values Tested
wtslp	0.1 - 1	0.3	0.1, 0.3, 0.5, 0.7, 1.0*
gamma	0.4 - 0.9	0.55	0.4*, 0.55, 0.7, 0.8, 0.9
facua	0 - 1	0.1	0, 0.1, (0.2)*, 0.4, 0.7, 1
fw	0 - 1	0	0, (0.08)*, 0.2, 0.5, 0.8, 1

***Final calibrated value**

Since the DUNERULE model is not based on initial and final profiles, but on volumetric properties, the calibration process differed from the SBEACH and XBEACH calibration process. An attempt was made to calibrate DUNERULE for water levels varying above and below the mean water level. Unfortunately, no reasonable calibration solution was found due to the following reasons:

- Only a constant water level elevation above the mean sea level could be modelled and therefore the tidal water level variation could not be modelled directly in the DUNERULE model.
- DUNERULE cannot predict coastal erosion for water levels below the mean sea level.

The calibration attempt evolved into an attempt to find a possible method through which DUNERULE can be used to predict cross-shore beach profile response under varying water level conditions. Unfortunately, no method was found through which DUNERULE could accurately predict beach profile response for both the 6.2-hour and 15.5-hour cases. The accuracy of DUNERULE to predict beach profile response under varying water levels was therefore not assessed.

5.5.1.2 Model Set-up

Since only one set of data was available to assess the accuracy of the selected numerical models in predicting beach profile response to water level variation, the experimental run was divided into separate cases. Twenty-three different water level variation cases were isolated from the CERC Large Wave Tank Case 911, by selecting different combinations of intermediate profiles as initial and final beach profiles. The initial and final profile survey times (in terms of the surveyed profiles of Case 911) are provided in Appendix D-3.

Six of the cases represented water level variation over 3 hours. Another six cases represented water level variation over 6 hours. Water level variation over 9 hours and 12 hours were represented by four cases each. Two cases with water level variation taking place over 24 hours were extracted and one case modelled the water level variation over the entire duration of Case 911. The model runs were numbered from Run 1 to Run 23 as indicated in Appendix D-3.

SBEACH and XBEACH were set up in a similar fashion as described for the calibration runs in Section 5.5.1.1. The time step for the SBEACH model runs was reduced to 12 seconds in order to provide results that are more accurate. No morphological acceleration factors were applied in the XBEACH model runs. The values of the calibration parameters were of course the same as those determined in Section 5.5.1.1. An assumption was made in XBEACH that the water density was that of seawater (1025kg/m^3). Afterwards it was realised that the water used in the flume experiments were probably fresh water with a density closer to 1000kg/m^3. Some model cases were rerun with the lower water density and it was found that the difference in cross-shore beach profile response was insignificant.

Run 1 to Run 23 were modelled with SBEACH and XBEACH after which the measured CERC Case 911 profiles were compared to the modelled profiles. The SBEACH and XBEACH model input parameter files for Run 23 are available in Appendix D-4 as example of general input.

5.5.2 Storm Duration

5.5.2.1 Model Calibration

Five CERC Large Wave Tank cases were selected (Section 4.3) to assess the accuracy of the selected numerical models in predicting cross-shore beach profile response under different storm durations. The numerical models were calibrated for the five cases that were studied.

The SBEACH and XBEACH calibration approaches remained the same as discussed in Section 5.5.1.1, where the calibration parameters were varied until the most accurate Brier Skill Scores and volumetric fits were achieved. Table 5-14 and Table 5-15 lists the calibration parameters and range of values that were used to calibrate each parameter for SBEACH and XBEACH respectively. The calibration model inputs were set up to represent the five different cases and the 5-hour and 15-hour intermediate profiles were used as calibration profiles. When a large difference existed between the 5-hour and 15-hour calibration results, calibration factors were selected based on the 15-hour profile results.

The SBEACH calibration model runs were all set up with a one-minute time step. The horizontal grid spacing was set to 1.2m, which corresponded with the horizontal spacing used during the profile surveys in the flume. The results of the SBEACH calibration runs for both calibration profiles in all five cases are provided in Appendix E-1. Table 5-16 provides the final values of the calibration parameters as deduced from the calibration runs.

Table 5-16: SBEACH Calibration Parameters for Storm Duration Verification

Calibration Parameter	**Case 300**	**Case 400**	**Case 500**	**Case 401**	**Case 501**
Transport Rate Coefficient (m^4/N)	1.5	2.5	1.75	1.75	2.0
Coefficient for Slope Dependent Term (m^2/s)	0.0025	0.0015	0.001	0.003	0.002
Transport Rate Decay Coefficient Multiplier	0.5	0.3	0.3	0.4	0.2
Depth Corresponding to Landward End of Surf Zone (m)	0.3	0.15	0.5	0.15	0.3
Maximum Slope Before Avalanching	30	30	30	30	30

A morphological acceleration factor (*morfac* = 10) was applied to decrease the model run times in XBEACH. Since this factor was only applied for the calibration model runs, the slightly less accurate results were not of consequence. The results of the XBEACH calibration runs for both calibration profiles in all five cases are provided in Appendix E-2. Table 5-17 provides the final values of the calibration parameters for XBEACH as deduced from the calibration runs.

Table 5-17: XBEACH Calibration Parameters for Storm Duration Verification

Calibration Parameter	**Case 300**	**Case 400**	**Case 500**	**Case 401**	**Case 501**
wtslp	0.8	0.3	0.1	0.1	0.3
gamma	0.4	0.55	0.8	0.6	0.4
facua	0.15	0.1	0	0.1	0.7
fw	0	0	0.1	0	0.5

Since the DUNERULE model is not based on initial and final profiles, but rather on volumetric properties, the calibration process differed from the SBEACH and XBEACH calibration process. For the CERC Large Wave Tank experimental runs the water level was kept at a constant level, which inherently implied that DUNERULE will predict no profile response. It was decided to use the water level as a calibration parameter. Therefore, the water level was adjusted until the most accurate erosion volumes above the water level were obtained, based on the 15-hour storm duration cases. The results of the DUNERULE calibration runs for both storm durations in all five cases are provided in Appendix E-3. Table 5-18 provides the final values of the calibration parameters as deduced from the calibration runs.

Table 5-18: DUNERULE Calibration Parameters for Storm Duration Verification

Calibration Parameter	**Case 300**	**Case 400**	**Case 500**	**Case 401**	**Case 501**
Water Level (m)	1.00	1.13	0.69	0.97	0.3

5.5.2.2 Model Set-up

The monochromatic wave conditions of the five different cases listed in Table 4-3 were used as input wave conditions in SBEACH, XBEACH and DUNERULE. The calibration parameters for the different numerical models, as discussed in Section 5.5.2.1, were entered for the different cases. The grid cell sizes (1.2m) for SBEACH and XBEACH were set up to represent the spacing at which the CERC Large Wave Tank profile measurements were taken. The time steps were set to one minute for the SBEACH model runs. No morphological acceleration was applied to the XBEACH model runs to ensure that the results were as accurate as possible.

In SBEACH and XBEACH, one numerical model run was done for each CERC Large Wave Tank experimental run from the initial profile to the final profile. The intermediate profiles, representing the shorter storm durations, were extracted from the overall model runs. In DUNERULE, each storm duration run was modelled separately. The model set-ups for SBEACH, XBEACH and DUNERULE for the assessment of the model accuracies in predicting Case 300's beach profile response to water level variation are provided in Appendix E-4.

5.5.3 Long Waves

5.5.3.1 Model Calibration

For the erosional cases, the models were calibrated using Run M_E of the physical data set described in Section 4.4. Run M_A was used to calibrate the models for cases of accretion. The two monochromatic experimental runs (with wave conditions provided in Table 4.4) were used for calibration, since these runs were used as base profiles to which the added free long waves and bichromatic waves were compared. The same calibration approach were used as described in Section 5.5.1.1.

SBEACH and XBEACH were both set up to model Run M_E and Run M_A as regular waves approaching the shore perpendicularly over 138 minutes. The surveyed profiles were measured at 0.02m horizontal intervals, which were too small to model in SBEACH. The grid spacing for SBEACH and XBEACH was therefore set to 0.1m, which was considered to be a fine enough grid cell size.

Initially a one-minute time step was applied in SBEACH, but it was found that the calibration results of the cross-shore beach profile response of Run M_E and Run M_A were not representative of the actual beach profile response. A time step of 12 seconds was then applied to the SBEACH model in an attempt to improve the accuracy of the model predictions. Unfortunately, no significant improvements were observed with the smaller time steps and even with the best calibration results, the Brier Skill Score and percentage volume eroded above the water level remained negative.

The water temperature at which the experiments commenced was assumed as 15°C, since the temperatures were not documented in the available data. Larson & Kraus (1988) noted that a difference in temperature between 5°C and 12°C has a negligible impact on the fall velocity used in the SBEACH model. It was therefore assumed that an inaccurate water temperature prediction would not cause significant differences in the SBEACH model runs. The results of the SBEACH calibration runs for the monochromatic erosional case are provided in Appendix F-1. The accretive calibration results are also provided in Appendix F-1.

In XBEACH, a morphological acceleration of 10 was applied to speed up the calibration process. The unknown water temperature was not of significance in XBEACH, since XBEACH uses a default and unchangeable temperature of 20°C. Although the XBEACH calibration results proved to be more accurate than the SBEACH calibration results, the Brier Skill Scores could not be improved to values above zero. The results of the XBEACH calibration runs for the monochromatic erosional and accretive cases are provided in Appendix F-2.

Since the calibration of neither SBEACH nor XBEACH provided beach profile responses that were representative of the actual measured beach profile responses for both the erosional and accretive cases, it was decided to set the calibration parameters to their default values (listed in Table 5-14 and Table 5-15 for SBEACH and XBEACH respectively). This way, the qualitative beach profile responses of SBEACH and XBEACH to long waves were still assessable. A possible explanation for the poor SBEACH and XBEACH model predictions is that the wave heights and periods of the experimental runs were very small. Both SBEACH and XBEACH were designed with the focus of predicting beach profile response of storm wave conditions and therefore, calm wave conditions might not be predicted that well.

Since DUNERULE does not have the ability to include long waves in its model set-up, DUNERULE was not included in this part of the study.

5.5.3.2 Model Set-up

In order to verify the accuracy of SBEACH and XBEACH in predicting beach profile response to long waves, physical data from large wave tanks as described in Section 4.4 were used. DUNERULE was not studied, due to its inability to include long waves in the model set-up. The two monochromatic wave cases that were used for model calibration were run in both SBEACH and XBEACH with default calibration parameters. The model monochromatic runs were used as base studies to which free and bound long wave model cases were compared.

To assess the accuracy of the numerical models in predicting cross-shore beach profile change due to free long waves, the three experimental runs for combined wave conditions (Run C_E4, Run C_A2 and Run C_A4) were replicated in the numerical models. Each numerical model had the same initial profile as the corresponding experimental run at the zero hour. Each model run was set up to predict beach profile response comparable with the final beach profiles from the experimental runs. In all the model runs the same calibration parameters (Section 5.5.3.1), sediment properties, water level and initial beach profiles were used as input.

In SBEACH and XBEACH the short waves were set up as constant regular waves and the long waves were set up as variation in water levels, since neither of the models have the option to specify individual free long waves. Although it is acknowledged that the variation of the water levels to replicate free long waves is not completely representative of the actual free long waves, this approach was the best solution to at least try to comprehend the effect of free long waves on beach profile response. Through this approach, the effect of the very small but frequent water level variation caused by free long waves was assessed even though other free long wave effects such as wave run-up and wave set-up were neglected.

In SBEACH a .ELV file was created to indicate the varying water level. The long waves were estimated to have a sinusoidal shape and the varying water elevations due to the movement of the long wave were provided for every second. The same information provided in the SBEACH .ELV file was copied in a .txt file referenced in XBEACH as a water elevation file. Figure 5-8 and Figure 5-9 shows the estimated long waves that were modelled in SBEACH and XBEACH as varying water levels. In order to ensure that the long wave water level variation was modelled as precisely as possible, a short time step of one second was used in SBEACH. No morphological acceleration factors were applied in XBEACH. The SBEACH and XBEACH configuration files for Run C_E4 are provided in Appendix F-3 as example of how the models were configured.

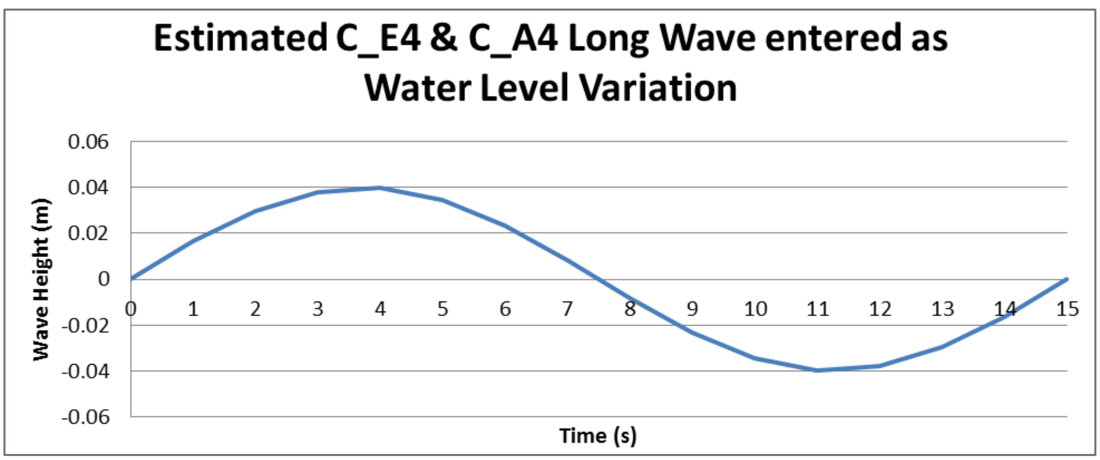


Figure 5-8: Estimated C_E4 & C_A4 Long Wave entered as Water Level Variation

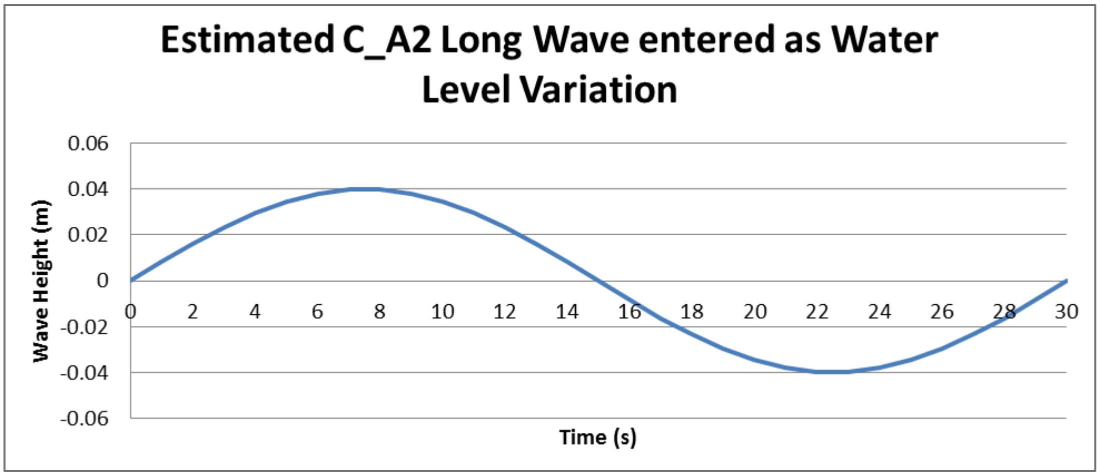


Figure 5-9: Estimated C_A2 Long Wave entered as Water Level Variation

SBEACH does not have the ability to model bichromatic waves, and thus only XBEACH's accuracy on predicting beach profile response to bound long waves were verified. In XBEACH the bichromatic wave regime must be specified using a single short wave and a governing long wave period. In other words, a root-mean-square short wave height, representative short wave period and short wave envelope period (long wave period) had to be specified. The root-mean-square wave height of the short waves were determined by superimposing the two short wave regimes for each model run over 120 seconds in Excel. The root-mean-square wave heights for each model run were calculated using:

$$H_{RMS} = \sqrt{\sum_{i=0}^{n} {H_i}^2/n} \qquad (4.11)$$

Where,

- H_{RMS} is the root-mean-square wave height (m)
- n is the number of time steps at which wave heights are classified
- H_i is the wave height at a specific time step 'i' (m)

XBEACH models the short wave period of the resulting waves due to superimposition as a constant wave period. In reality, the short wave period of consecutive waves vary slightly. In order to obtain the most accurate bichromatic wave regime, the short wave periods were estimated from the Excel data by averaging the superimposed short wave periods.

The bound long wave period was also determined from the Excel data, by determining the time between the short wave envelope nodes. This process of determining the long wave period is illustrated in Figure 5-10. The bichromatic short wave and long wave data that was used as input in each XBEACH model run is provided in Table 5-19. Appendix F-4 shows the model input for Run B_A2 as indication of the typical set-up used to model the bichromatic wave conditions in XBEACH.

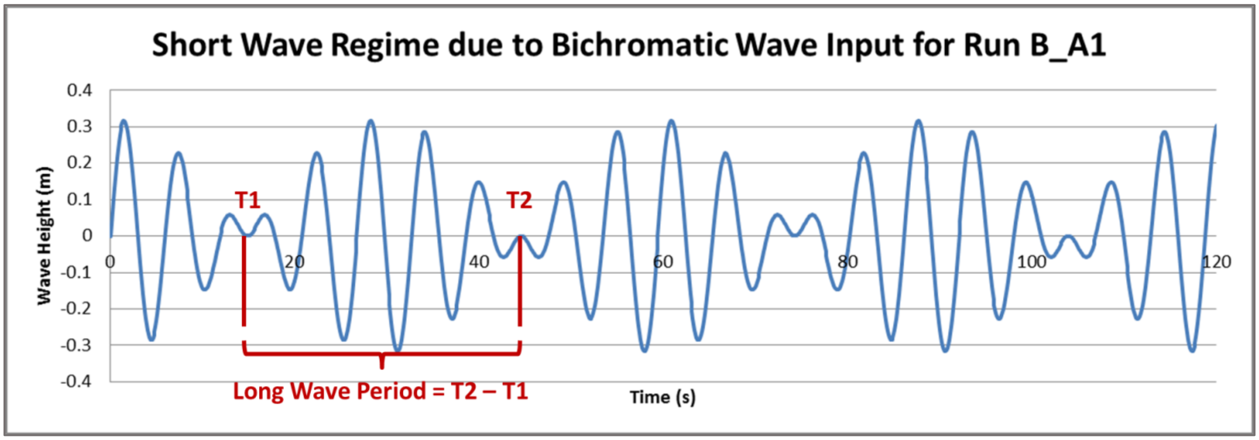


Figure 5-10: Determining Bound Long Wave Period Generated Through Bichromatic Wave Conditions

Table 5-19: Bichromatic Wave Input for XBEACH

Run	**H_{RMS} (m)**	**T_{rep} (s)**	**T_{long} (s)**	**Duration (min)**
		Initial		
B_E1	0.26	3.50	34	138
B_E2	0.26	3.28	15	138
B_A1	0.16	6.60	29	138
B_A2	0.16	4.73	15	138

6 Analysis and Results of Model Sensitivity to Changing Parameters

6.1 Sediment Transport Parameters Analysed

6.1.1 Overview

The analysis of the results included determining the absolute sediment volume difference between the final and initial cross-shore beach profiles. The maximum averaged sediment transport rates were also obtained for all cases. Other parameters that are of importance for coastal design that were analysed, include the total volume of erosion or accretion above the water level, as well as the mean and maximum recession of the shoreline.

6.1.2 Absolute Volume of Sediment Displaced

Since longshore sediment transport is neglected in this study, the total volume of erosion or accretion of the beach profiles is zero, or close to zero. The explanation is that conservation of mass takes place, meaning that no sediment can enter or exit the system, unless it is artificially added or carried offshore to submarine canyons during extreme conditions. Sometimes negligible differences exist between the modelled erosion and accretion, but theoretically the same amount of sediment volume accretes per unit length (Area B) over a cross-shore beach profile as the amount of sediment volume that erodes (Area A) over the profile as illustrated in Figure 6-1.

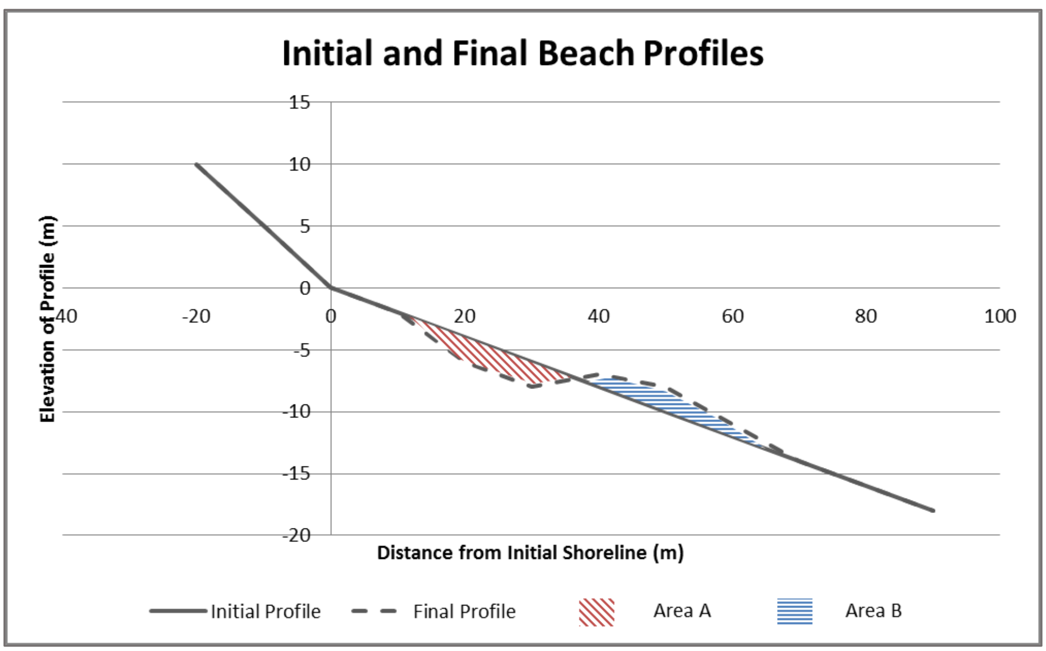


Figure 6-1: Areas of Erosion and Accretion between Initial and Final Beach Profiles

It is, however, possible to determine the absolute volume of sediment displaced between the initial and final profiles by observing the absolute volume of accreted and eroded sediment over the entire profile. Between the initial and final profiles, more sediment could have eroded or accreted at a specific point, but this is, however, neglected in this study where only the initial and final profiles were analysed.

The approach to determine the absolute sediment volume displaced, is simple. The absolute volume displacement (m^3/m) between the initial and final profiles was calculated, using the equation:

$$V = \int_{x_0}^{x} |(y_2 - y_1)| dx \tag{5.1}$$

Where,

- V is the absolute volume of sediment displaced in m^3/m
- y_1, y_2 are the initial and final profile elevations in m
- x_0, x are the horizontal boundaries of sediment transport

Theoretically, the amount of deposited sediment is equal to the amount of eroded sediment and thus equal to half of the absolute displaced sediment volume.

6.1.3 Eroded Volume of Sediment above Water Level

The change of beach profiles above the sea level is of critical importance for development projects near the coast. It is therefore important to know how beaches erode or accrete above the sea level due to for example wave run-up. In DUNERULE the total volume of sediment eroded above the sea level is provided in the output. However, when comparing erosion or accretion between initial and final profiles, a similar equation to Equation 5.1 is used:

$$V = \int_{x_0}^{x_{sl}} (y_2 - y_1) dx \tag{5.2}$$

Where,

- V is the volume of eroded sediment in m^3/m
- y_1, y_2 are the initial and final profile elevations in m
- x_0 is the distance from MSL to the landward boundary of sediment transport (m)
- x_{sl} is the distance from the mean sea level to the sea level used in the model

6.1.4 Maximum Averaged Sediment Transport Rate

Cross-shore sediment transport of beaches can be quantified through numerous methods. One of the simpler methods is to calculate the average cross-shore sediment transport rate distribution based on the conservation of mass. This method is commonly used and was for instance applied in a study done by Larson & Kraus (1989).

$$q(x) = \frac{1}{t_2 - t_1} \int_{x_0}^{x} (y_2 - y_1) dx \tag{5.3}$$

Where,

- $q(x)$ is the net sediment transport rate across the beach profile (m^3/m/h)
- t_2, t_1 is the times at which the final and initial beach profiles were measured (h)
- y_1, y_2 is the initial and final beach profile depths at times t_1 and t_2 (m)
- x_0, x is the landward and seaward location of no beach profile change

Figure 6-2 shows an example of an average cross-shore sediment transport rate distribution. For this study the absolute maximum transport rate (m^3/m/h) was used as a key parameter in determining the sensitivity of the different models to varying conditions. The absolute maximum transport rate may be in either an onshore or offshore direction and is indicated in Figure 6-2.

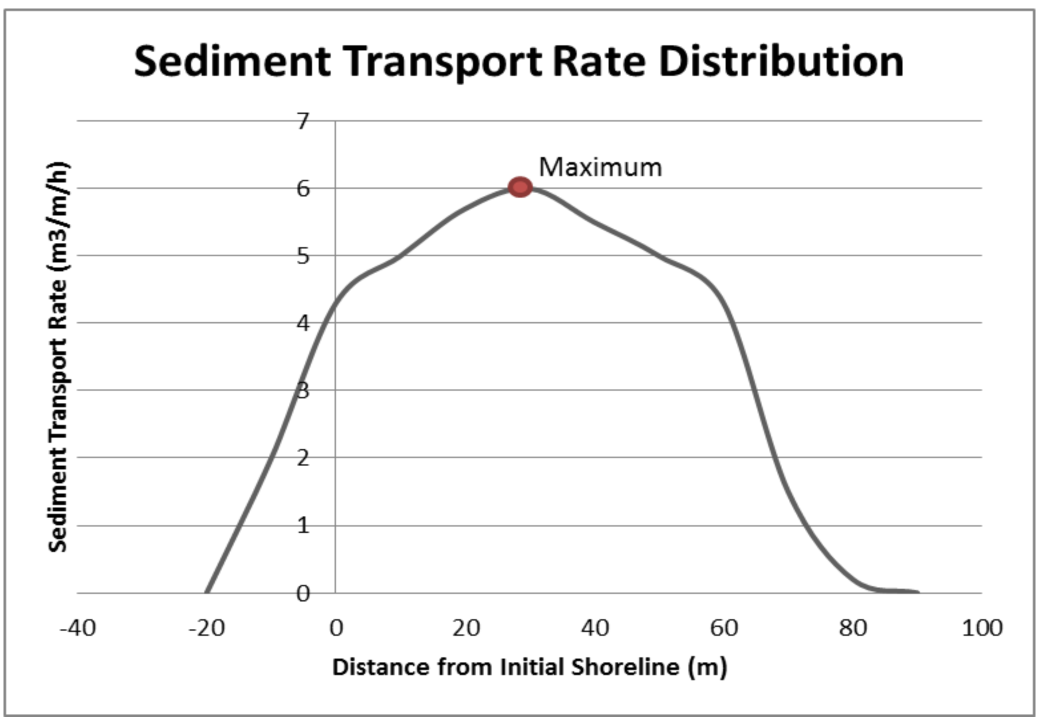


Figure 6-2: Example of Sediment Transport Rate Distribution

6.1.5 Position of Maximum Sediment Transport Rate

All the parameters mentioned in Section 6.1.2 to Section 6.1.4 (Absolute Volume of Sediment Displaced, Total Amount of Sediment Transported Above Sea Level and Maximum Averaged Sediment Transport Rate) are parameters indicating volumetric beach profile response. It is, however, possible that the volumetric response of a beach is similar for two different conditions, but that the volumetric response occurs at different positions along the beach profile.

In order to accommodate the location of sediment transport in the sensitivity analysis of beach profiles to varying parameters, the position of maximum sediment transport rate was incorporated in the study. The position of maximum sediment transport was merely determined by finding the corresponding horizontal position of the maximum sediment transport rate as illustrated in Figure 6-3. No new calculations were necessary, since the position of maximum sediment transport rate could be determined from the same data used in Section 6.1.4.

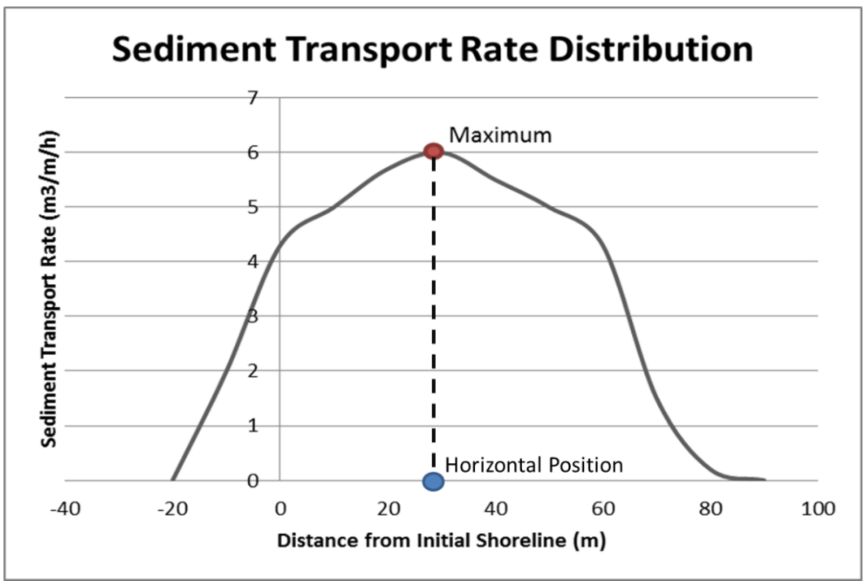


Figure 6-3: Example of Position of Maximum Sediment Transport Rate

6.1.6 Recession of Shoreline

Another valuable parameter of beach profile change is shoreline recession. The recession of the elevation contour at which the sea level is specified is regarded as the shoreline recession in study. It is possible that the maximum recession of the shoreline occurs at a time between the start and stop of the specific impact conditions, but in this study only the shoreline recession from the initial to the final beach profile is analysed.

In XBEACH and SBEACH the final and initial beach profiles are provided in terms of the y-coordinates at set x-coordinate grid points. If the water elevation contour migrated horizontally, it is indicative of shoreline movement. If the water elevation contour migrated landward, it means that shoreline recession took place and *vice versa*. DUNERULE directly provides the modelled shoreline recession in its output.

In order to determine the recession of a shoreline, the water elevation contour of the initial profile was identified. The identified elevation contour was traced horizontally in order to locate the new position of the elevation contour along the x-axis. The migration distance of the elevation contour is determined by subtracting the final horizontal location of a specific elevation contour from the initial horizontal location. An example of the recession distance of an elevation contour is shown in Figure 6-4.

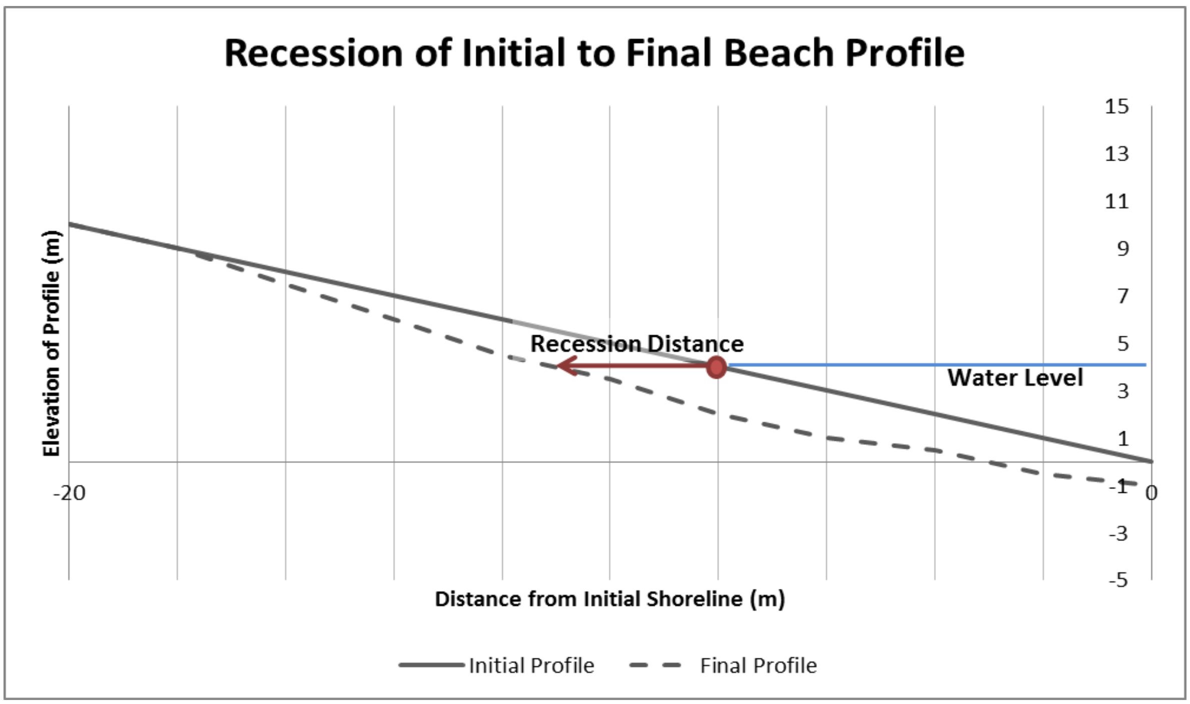


Figure 6-4: Example of Determining Shoreline Recession of the Water Elevation Contour

6.2 Sea Level Variation

6.2.1 Overview of Model Sensitivity Analysis to Sea Level Variation

There were 33 model runs that had to be run with each of the three models: SBEACH, XBEACH and DUNERULE. Some of these models could not run all 33 cases due to exceptions summarized in Table 6-1.

Table 6-1: Model Run Exceptions

Model	Runs Not Modelled	Reason
DUNERULE	1.7 to 1.11 2.7 to 2.11 3.7 to 3.11	DUNERULE only models for water levels above mean sea level, since it is mainly a model to determine the impact of storms which include storm surge.

Figure 6-5 and Figure 6-6 shows the initial and final cross-shore beach profiles as generated by SBEACH and XBEACH respectively for a random case, Run 3.3. The output of the DUNERULE model was a dune erosion volume of 119m^3/m and a maximum shoreline recession of 10.5m after twelve-hour impact. The initial and final beach profiles for all the SBEACH and XBEACH runs, as well as the DUNERULE results are provided in Appendix A-3.

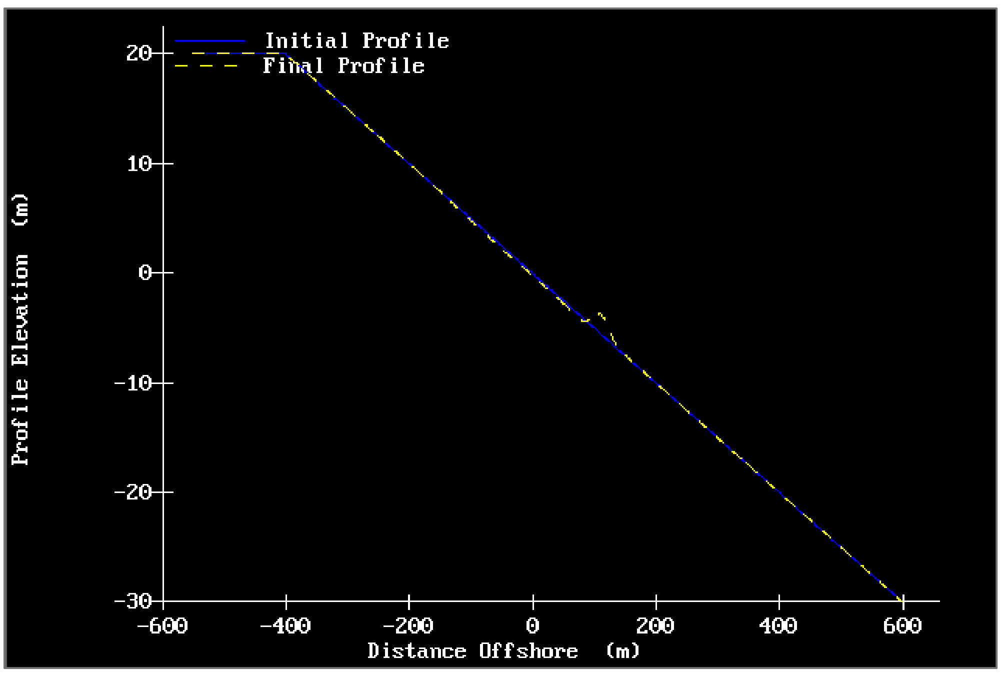


Figure 6-5: Water Level Variation - Initial and Final Beach Profiles of Case 3.3 for SBEACH

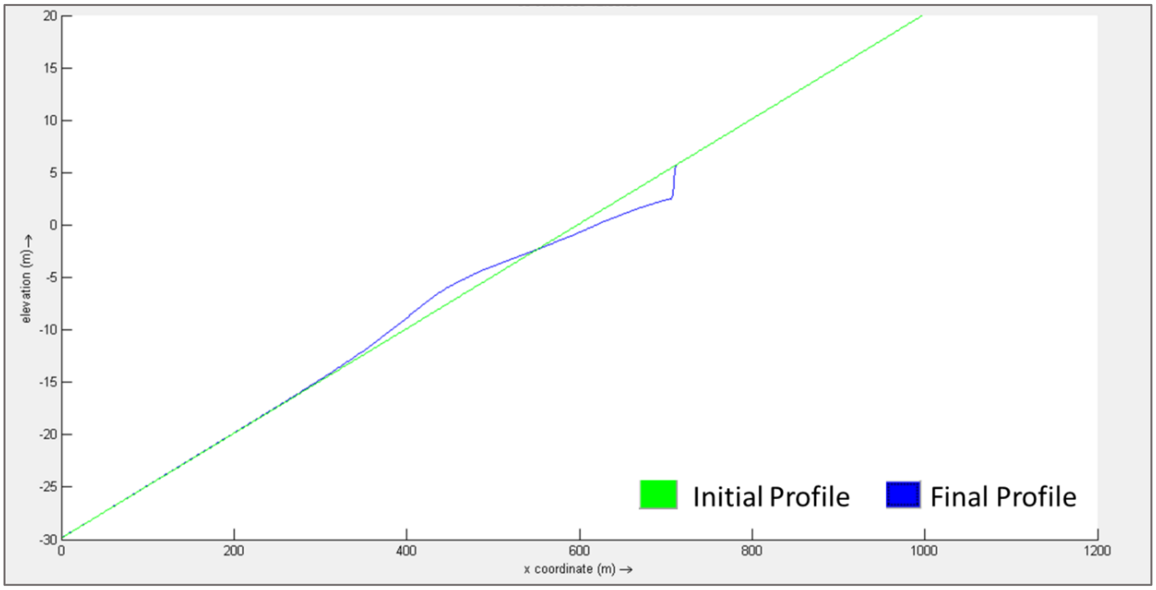
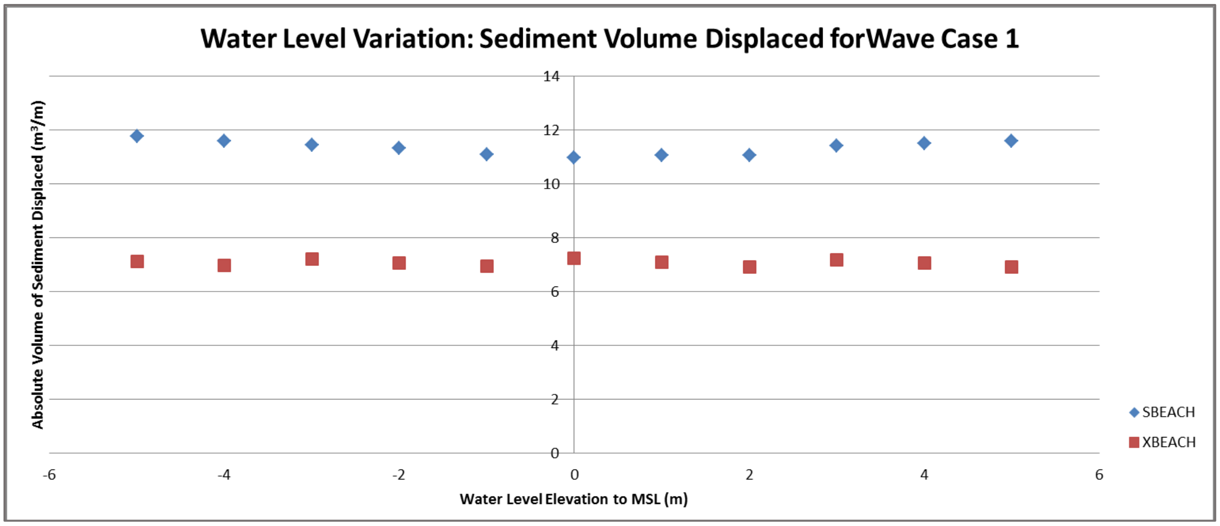


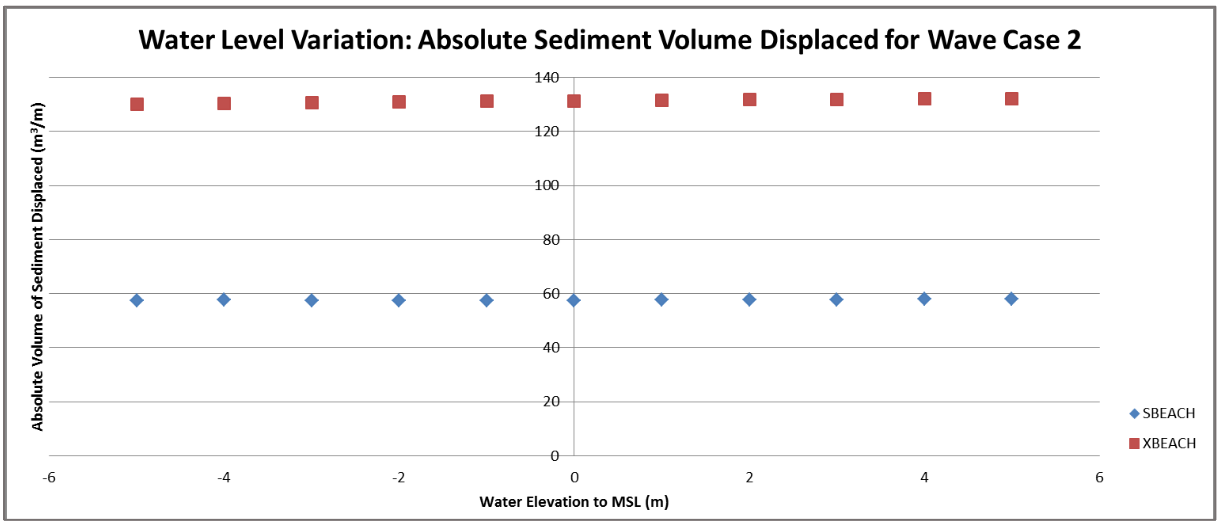
Figure 6-6: Water Level Variation - Initial and Final Beach Profiles of Case 3.3 for XBEACH

6.2.2 Absolute Volume of Sediment Displaced

In order to analyse the sensitivity of the different numerical models to water level variation, the absolute volume of sediment displaced were calculated for 11 different water levels under three different wave conditions using different numerical models. DUNERULE does not provide enough information in its output to derive the absolute volume of sediment displaced. Therefore, only the sensitivity of SBEACH and XBEACH to variation in water levels were studied by analysing the absolute sediment transport volumes. For each wave condition (Case 1 to Case 3), the absolute volume of displaced sediment volumes (tables in Appendix A-4) were plotted against 11 different water levels. These graphs are provided in Figure 6-7a to Figure 6-7c.

For Wave Case 1 (calm conditions), both SBEACH and XBEACH showed no significant sensitivity to water level variation. SBEACH indicated nearly the same absolute volume displacements for all the different water levels without any clear increase or decrease as the water level increased and so did XBEACH. Another observation was made that the absolute displaced sediment volumes of XBEACH was about 60% of the absolute displaced sediment volumes of SBEACH.





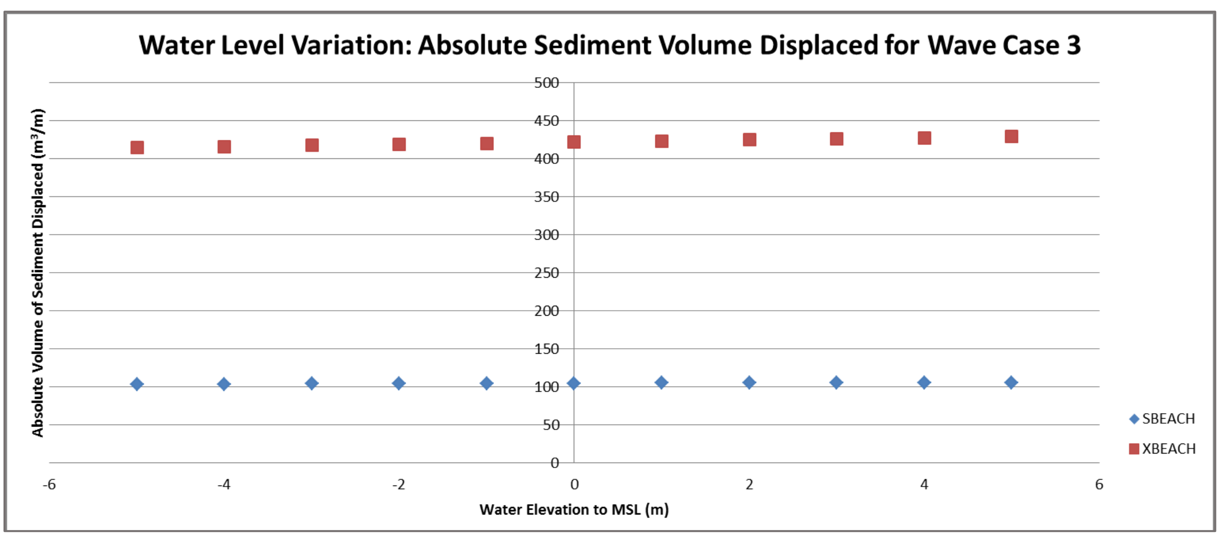


Figure 6-7: Absolute Sediment Volume Displaced due to Water Level Variation for (a) Wave Case 1, (b) Wave Case 2 and (c) Wave Case 3

For Wave Case 2 (moderate conditions), the sensitivity of SBEACH to water level variation remained insignificant. There was no clear trend of absolute sediment volume displacement increase or decrease as the water level increased. XBEACH, on the other hand, showed a slight relationship between the water level and the absolute volume of displaced sediment. As the water level increased, the absolute volume of displaced sediment increased ever so slightly from 130.06m^3/m to 132.06m^3/m. Furthermore, the XBEACH results were more than twice as large as the SBEACH results.

For Wave Case 3 (extreme conditions), both SBEACH and XBEACH exhibited a clear relation between the water level and the absolute volume of displaced sediment. Both models showed a slight but consistent near-linear increase in absolute displaced sediment volumes as the water level increased. The absolute displaced volume of sediment in SBEACH increased from 103.52m^3/m to 105.81 m^3/m as the water level increased. This increase was insignificant, since it is probably less than the accuracy limits of the model. The absolute displaced volume of sediment in XBEACH increased from 414.70m^3/m to 428.81m^3/m as the water level increased. The difference between the SBEACH and XBEACH results, however, increased even further, with the XBEACH results being more than four times bigger than the SBEACH results.

In the next few paragraphs, a theoretical explanation is provided as to why the absolute displaced sediment volume increased as the water levels increased and why the effect is more significant for more extreme wave conditions. Firstly, it must be understood that waves start shoaling as the waves enter transitional water depths. When a wave reaches a depth of about half its wavelength, it starts to be influenced by the ocean floor. From this point on the ocean floor exerts a force on the bottom of the wave, resulting in the wave slowing down. Since consecutive waves start slowing down at different times, the waves become compressed, decreasing in wavelength and increasing the wave height (Chadwick *et al.*, 2004). Through this process the kinetic energy of the wave is converted to potential energy that has to be dissipated by wave breaking and impact with the beach face.

SBEACH and XBEACH both registered the input wave heights as the wave heights at the offshore boundary of the input profile. All the wave heights are thus classified at a depth or 30m to mean sea level. In Table 6-2, the water depths to the specified sea level elevation at which the waves enter the transitional zone are provided for Wave Case 1 to Wave Case 3. The formula by which the wavelengths were calculated are provided in Table 2-6.

Table 6-2: Offshore Depths of Transition Zones for Wave Case 1 to Wave Case 3

Wave Case	Wave Period (s)	Wave Length (m)	Offshore depth of Transition Zone (m)
1	6	56.00	28.00
2	12	223.99	112.00
3	16	398.21	199.10

In Wave Case 2 and Wave Case 3 the input waves were already in the transitional wave zone and the waves were thus already shoaling. In Wave Case 1, the waves started shoaling at a water depth of 28m to the specified sea level elevation. Therefore, the waves in Run 1.1 to Run 1.7 were the only waves that have not started shoaling at the shoreward boundary of the input profiles. Run 1.8 to Run 1.11 have input wave depths of less than 28m.

The waves in the model runs with higher water levels and input water depths that were less than the offshore depths of the transition zone, experienced more shoaling, since they traveled over a longer horizontal distance. A larger shoaling distance theoretically leads to waves with shorter wavelengths, higher wave heights and more potential energy.

Waves with more potential energy exert larger forces on the beach face during the dissipation process. The fact that the waves can theoretically reach higher heights and contain more potential energy when the water level elevation is higher, explains why an increase in absolute displaced sediment volumes is plausible for an increase in water level elevation. Both SBEACH and XBEACH short wave propagation was based on linear wave theory and yet a significant difference in absolute displaced sediment volumes is obtained between these two models. The significant difference can be explained by the different default breaker indices in the wave breaking formulations of the sediment transport models used by SBEACH and XBEACH. The overall sediment transport formulations may also have caused the differences. Since no calibration of the models was done, it is possible that part of the observed difference can be attributed to the different data sets to which SBEACH and XBEACH were respectively calibrated to during the model developments.

In Run 1.1 to Run 1.7 the waves traveled the same distance from the point where shoaling started until they dissipated completely, since the beach face had a constant slope. The waves thus built up the same amount of energy before they started breaking and thus exerted the same force onto the seafloor. The resulting absolute volume of displaced sediment were thus equal in all the runs, explaining why no increase in absolute volume of displaced sediment occurred.

6.2.3 Eroded Volume of Sediment above Water Level

The eroded volume of sediment above the specified water levels for the different model runs was analysed, since it is more representative of the area where damage to structures above the water level might occur. In order to analyse the sensitivity of the different numerical models to water level variation, the total volume of sediment eroded above the specified water levels were calculated for 11 different water levels under three different wave conditions using different numerical models. All three models provided output that was sufficient to determine the eroded volume of sediment above the water level. For each wave condition (Case 1 to Case 3), the eroded volume of sediment above the specified water levels (tables in Appendix A-4) were plotted against 11 different water levels. DUNERULE only models for water levels above the mean sea level; thus, no DUNERULE results were obtained for water levels between -1m and -5m to mean sea level. The graphs are provided in Figures 6-8a to Figure 6-8c.

For Wave Case 1 (calm conditions), both SBEACH and XBEACH showed no significant sensitivity to water level variation. SBEACH indicated nearly the same volume of eroded sediment above the specified water level for all the different water levels without any clear linear increase or decrease as the water level increased and so did XBEACH. XBEACH showed eroded volume values of almost zero, where SBEACH showed values ten times bigger than the XBEACH values. DUNERULE exhibited extreme sensitivity to water level variation with a near linear increase in eroded sediment volumes as the water levels were increased which is consistent with the DUNERULE model approach.

For Wave Case 2 (moderate conditions), the sensitivity of SBEACH and XBEACH to water level variation remained insignificant. There was no clear trend of eroded volume increase or decrease with an increase in water level elevation. Furthermore, the XBEACH results were three times larger than the SBEACH results. DUNERULE again exhibited extreme sensitivity to water level variation.

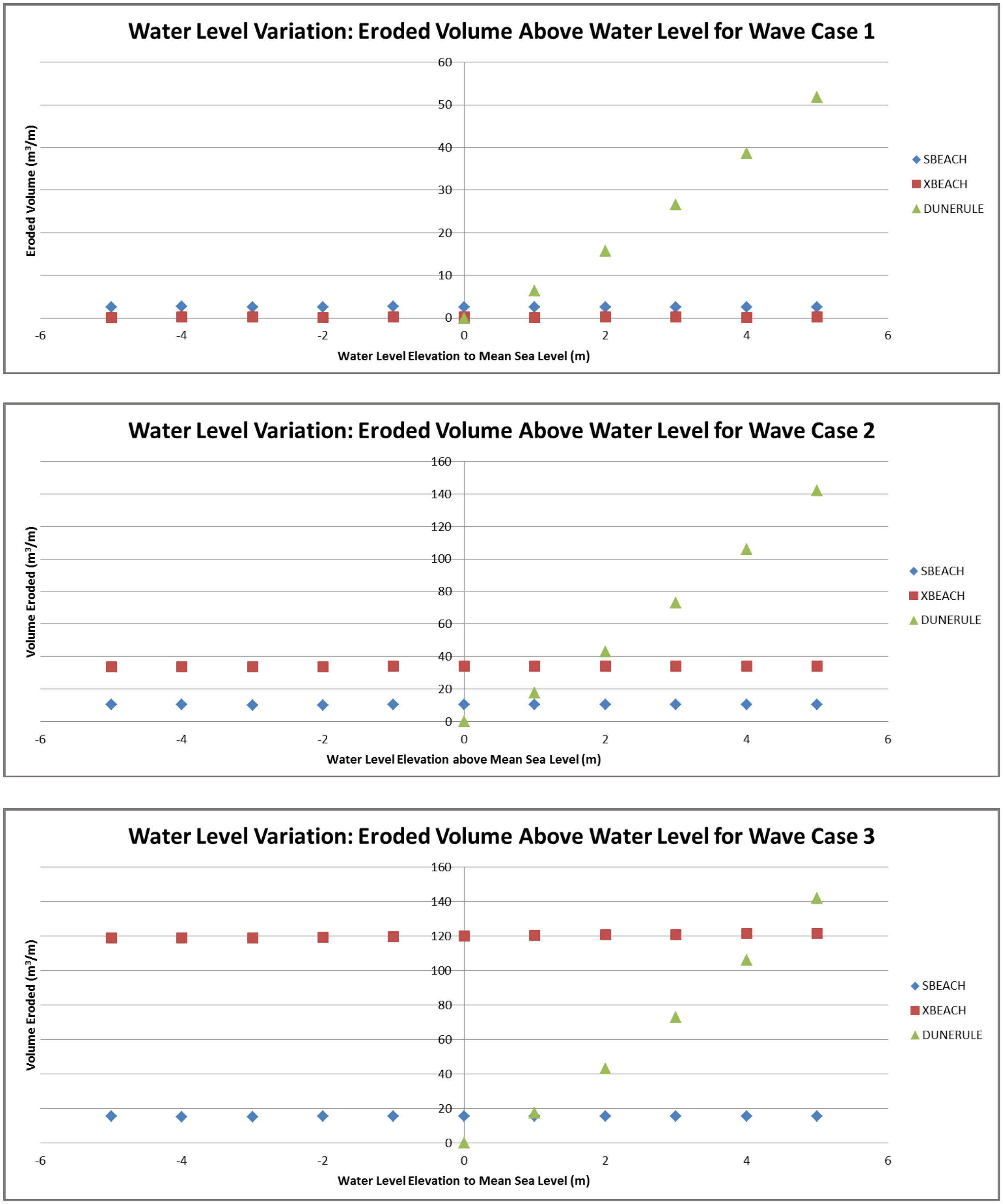


Figure 6-8: Transported Sediment Volumes Above Specified Water Levels due to Water Level Variation for (a) Wave Case 1, (b) Wave Case 2 and (c) Wave Case 3

For Wave Case 3 (extreme conditions), SBEACH still showed no relation between sea level variation and the amount of sediment eroded above the specified water level elevation. XBEACH on the other hand exhibited a small but noticeable increase in the volume of sediment eroded above the water level and the water level elevation. The volume of eroded sediment above the specified water level in XBEACH increased from $118.7m^3/m$ to $121.5m^3/m$. The difference between the SBEACH and XBEACH results increased even further, with the XBEACH results being seven to eight times that of the SBEACH results. As in Wave Case 1 and Wave Case 2, DUNERULE exhibited extreme sensitivity to water level variation.

From the results, it would appear that SBEACH is not sensitive to water level variation based on the effect of water level variation on the eroded volume of sediment above the specified water level. A relation between the water level and the eroded sediment volume above the water level might be observed for more extreme wave conditions. Based on the data from this study no sensitivity was observed.

XBEACH indicated sensitivity to water level variation for the third and more extreme wave condition, since the volume of eroded sediment increased along with the increase in the water level. This observation can be explained using the same shoaling explanation as in Section 6.2.2. The horizontal distance that a wave has to travel before it breaks, increases as the water level increases. Due to the longer travelling distance, more wave shoaling takes place resulting in higher wave heights before wave breaking takes place. Waves with a higher wave height (and thus higher potential energy) will run further up the beach slope before breaking and dissipating all the wave energy. Higher wave run-up increases the beach area above the water level, that is impacted by the waves. A larger area is thus exposed to possible sediment transport. Once again the large difference between the SBEACH and XBEACH results can possibly be attributed to the different wave propagation and dissipation models.

DUNERULE is a model that is based on a specific base study. All the output parameters are calculated in relation to the original base study results. The increase in eroded volumes is a function of $\left(\frac{x}{5}\right)^{1/3}$ (where x is the specified water level to mean sea level), which explains why a large increase in eroded volumes above the water level occurred when the sea level increased.

6.2.4 Maximum Averaged Sediment Transport Rate

Another factor studied in order to analyse the sensitivity of the different numerical models to water level variation, was the maximum averaged sediment transport rate. DUNERULE does not provide enough information in its output to derive the maximum averaged sediment transport rate. Therefore, only the sensitivity of SBEACH and XBEACH to variation in water levels were studied by analysing the maximum averaged sediment transport rates. For each wave condition (Case 1 to Case 3), the maximum averaged sediment transport rates (sediment transport rate distribution graphs provided in Appendix A-5) were plotted against 11 different water levels. Negative sediment transport rates indicate offshore sediment transport. These graphs are provided in Figures 6-9a to Figure 6-9c.

For Wave Case 1 (calm conditions), both SBEACH and XBEACH showed no significant sensitivity to water level variation. SBEACH indicated nearly the same maximum averaged sediment transport rate for all the different water levels without any clear linear increase or decrease as the water level increased and so did XBEACH. The maximum averaged sediment transport rates of SBEACH was about one and a half times larger in the offshore direction than the XBEACH transport rates.

For Wave Case 2 (moderate conditions), the sensitivity of SBEACH to water level variation remained insignificant. There was no clear trend of maximum averaged sediment transport rate increase or decrease as the water level increased. XBEACH on the other hand showed a slight linear relationship between the water level and the maximum averaged sediment transport rate. As the water level increased, the maximum averaged sediment transport rate increased ever so slightly from 5.4m^3/m/h to 5.5m^3/m/h, indicating insignificant increase. Furthermore, the XBEACH sediment transport rates were 240% larger in the offshore direction than the SBEACH results.

For Wave Case 3 (extreme conditions), both SBEACH and XBEACH exhibited a clear relation between the water level and the maximum sediment transport rate. Both models showed a slight but consistent near-linear increase in maximum sediment transport rates as the water level increased. The maximum averaged sediment transport rates in the offshore directions increased from 4.29m^3/m/h to 4.40m^3/m/h for SBEACH and from 17.36m^3/m/h to 17.89m^3/m/h for XBEACH as the water level increased. The increases observed in SBEACH and XBEACH were both rather small and are probably insignificant.The difference between the SBEACH and XBEACH results increased even further, with the XBEACH results being four times larger than the SBEACH results.

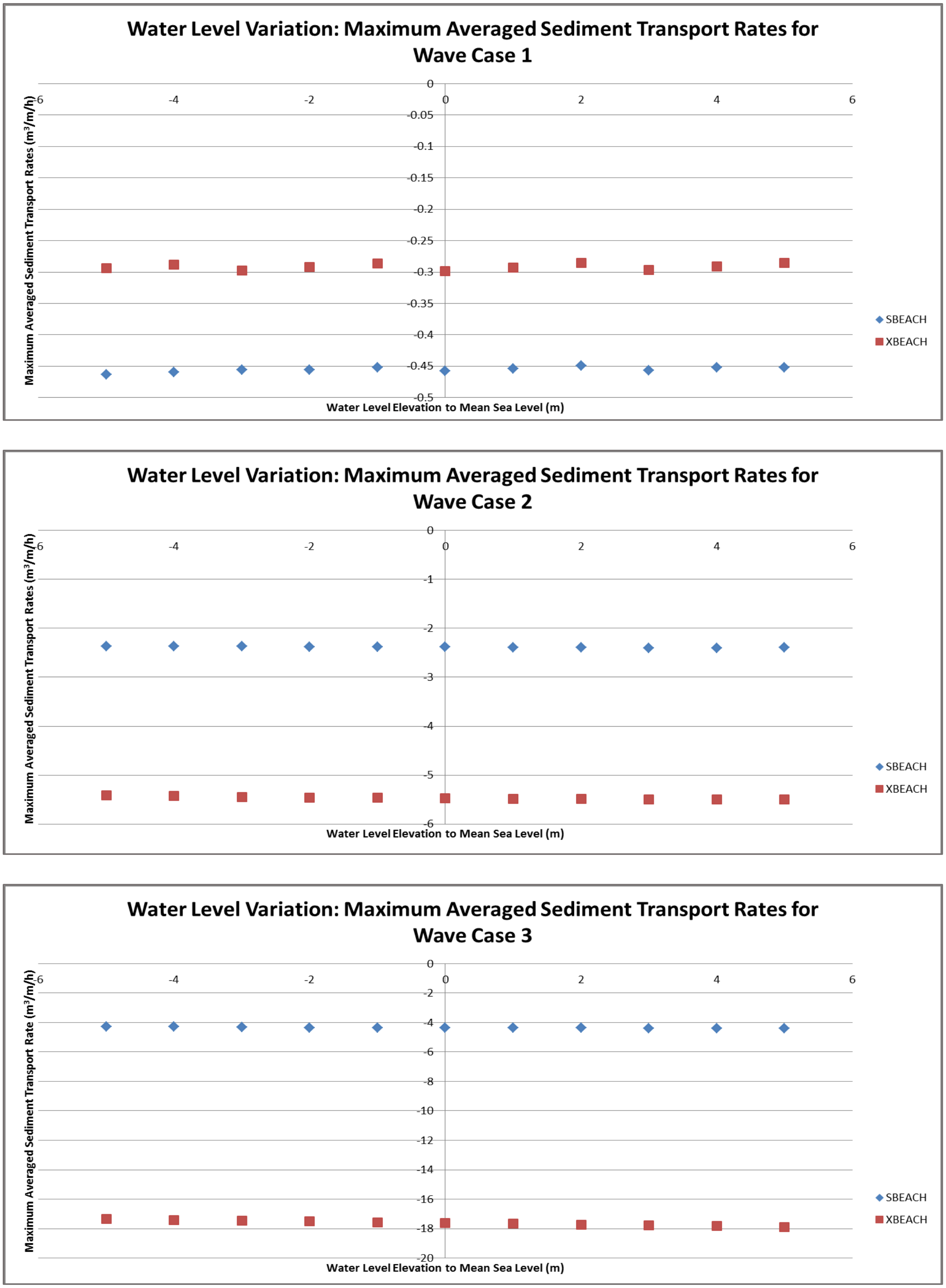


Figure 6-9: Maximum Averaged Sediment Transport Rates due to Water Level Variation for (a) Wave Case 1, (b) Wave Case 2 and (c) Wave Case 3

The maximum averaged sediment transport rate relation to water level variation was similar to the relationship between the absolute amount of sediment displaced and the water level variation as discussed in Section 6.2.2. Neither SBEACH nor XBEACH showed any relation for Wave Case 1. In Wave Case 2, XBEACH showed a minor increase in maximum sediment transport rates as the water levels increased. SBEACH remained insensitive to water level variation in Wave Case 2. Both SBEACH and XBEACH showed sensitivity to water level variation for Wave Case 3, since both showed increases in the maximum averaged offshore sediment transport rates as the water levels increased.

The explanation for the above mentioned observations is once again that the shoaling distance for Wave Case 1 remains practically the same for all water level elevations. Therefore, the lack of sensitivity to water level variation that was observed in SBEACH and XBEACH is justified.

In both Wave Case 2 and Wave Case 3, the differences in shoaling distances (as discussed in Section 6.2.2) explains why slight increases were observed in the maximum averaged sediment transport rates as water level elevations increased. More potential energy is built up in waves that travel over larger shoaling distances. A larger force is thus exerted onto the beach face during wave energy dissipation. Larger forces cause more bottom sediment to be disturbed and larger sediment transport rates are thus observed. The differences in the SBEACH and XBEACH data can again be attributed to the fact that different wave and sediment transport formulations are used.

6.2.5 Position of Maximum Sediment Transport Rate

The only non-volumetric factor that was studied to analyse the sensitivity of the different numerical models to water level variation, was the position of the maximum averaged sediment transport rate. The position of the maximum averaged sediment transport rate was calculated for 11 different water levels under three different wave conditions. Only the sensitivity of SBEACH and XBEACH to variation in water levels were studied through the analysis of the position of the maximum averaged sediment transport rates. For each wave condition (Case 1 to Case 3), the position of the maximum averaged sediment transport rates (sediment transport rate distribution graphs provided in Appendix A-5) was plotted against 11 different water levels. These graphs are provided in Figure 6-10a to Figure 6-10c.

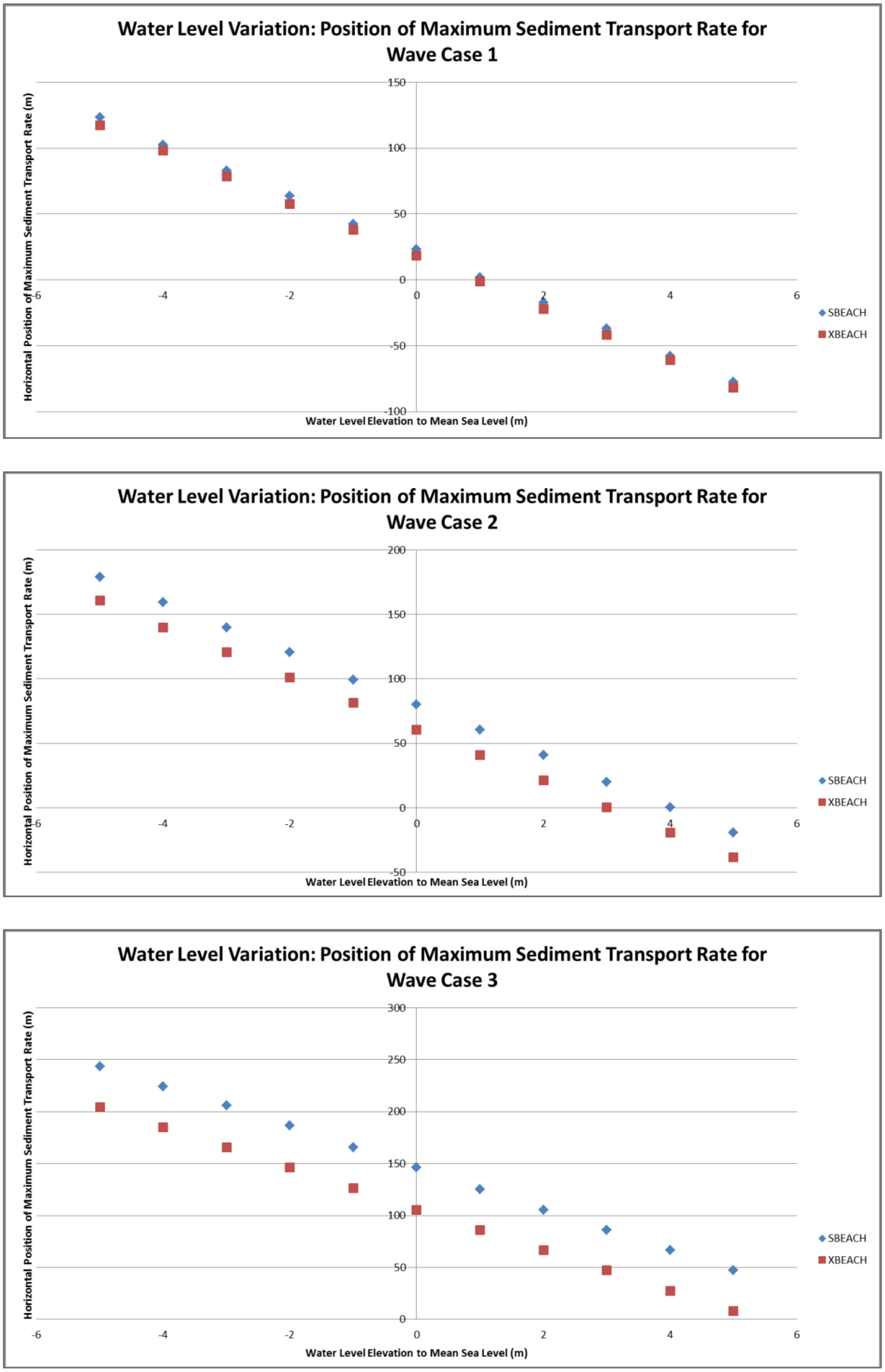


Figure 6-10: Position of Maximum Averaged Sediment Transport Rates due to Water Level Variation for (a) Wave Case 1, (b) Wave Case 2 and (c) Wave Case 3

Both SBEACH and XBEACH showed an expected linear shift of the position of the maximum averaged sediment transport rate as the water level increased. In Wave Case 1, SBEACH and XBEACH had very similar results, where the position shifted from a distance of 120m landward of the mean sea level to a distance 80m offshore from the mean sea level as the water level lowered.

In Wave Case 2 and Wave Case 3, the difference between the SBEACH and XBEACH positions of the maximum averaged sediment transport rates grew further apart. Both SBEACH and XBEACH, however, maintained a linear shift in position as the water level lowered. For each 1m drop in water level, the position of the maximum sediment transport rate shifted approximately 20m offshore. The modelled beach profile had a slope of 1:20, which explains why the modelled horizontal shifts were all more or less 20m/m. The average offshore shift per 1m drop in water level decreased ever so slightly from Wave Case 1 to Wave Case 3. Table 6-3 indicates the average offshore shift per 1m drop in water level as observed from the SBEACH and XBEACH results for all three wave cases.

Table 6-3: Horizontal Shift of Position of Maximum Averaged Sediment Transport Rate per 1m Drop in Water Level

Wave Case	SBEACH Shift (m/m)	XBEACH Shift (m/m)
1	20.09	19.92
2	19.86	19.94
3	19.77	19.70

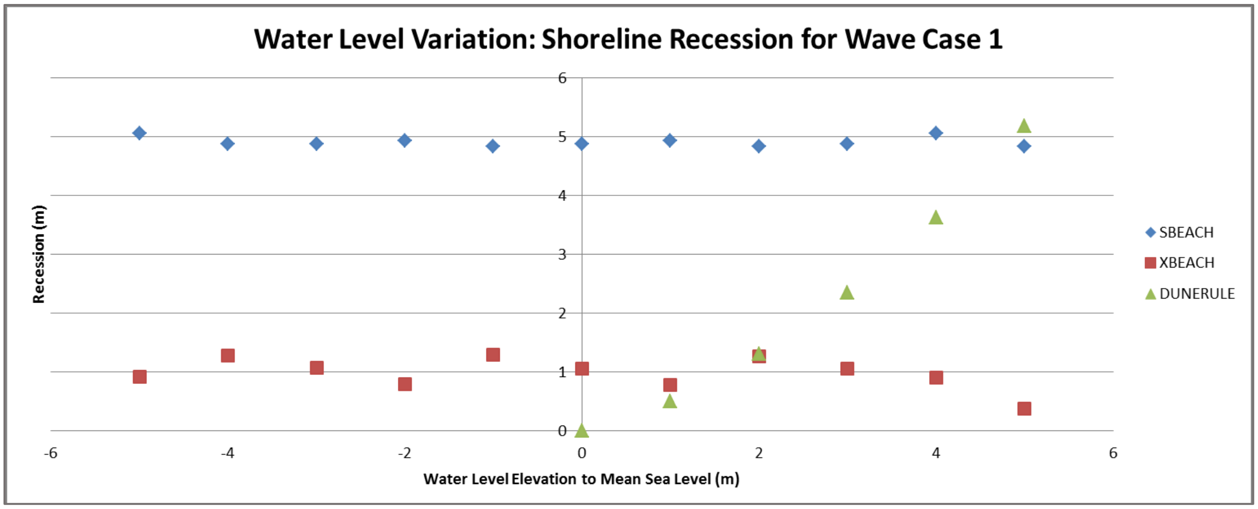
The shifts of the horizontal positions were all very similar and the differences are probably not of significance. The effects of shoaling may contribute to the slight variation in the horizontal shifts per 1m drop in water level, as explained in Section 6.2.2. A shift of the horizontal position will be higher for water levels dropping from +5m to +4m to mean sea level than for water levels dropping from -4m to -5m to mean sea level. The differences in the locations of the horizontal positions where the maximum sediment transport rates occurred in SBEACH and XBEACH, are most probably due to the different methods (Section 5.2) through which the models predict sediment transport.

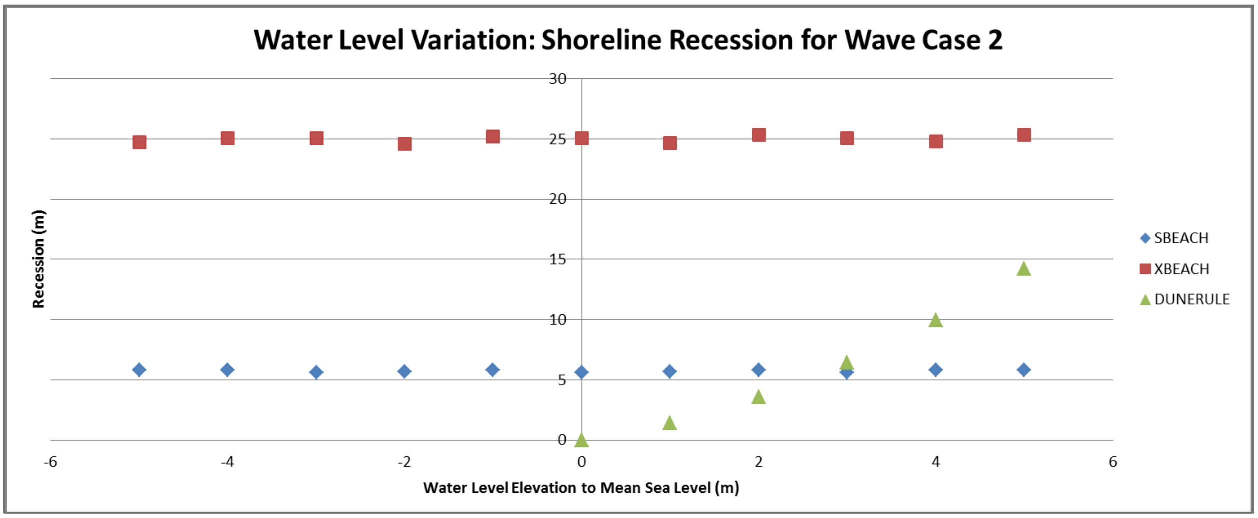
6.2.6 Recession of Shoreline

The recession of the shoreline at the specified water levels for the different model runs was analysed, since it is an important measure of the impact of the wave conditions, especially during storms. In order to analyse the sensitivity of the different numerical models to water level variation, the recession of the shoreline at the specified water levels was calculated for 11 different water levels under three different wave conditions using different numerical models. All three models (SBEACH, XBEACH and DUNERULE) provided output that was sufficient to determine the shoreline recession at the water level. For each wave condition (Case 1 to Case 3), the shoreline recession at the specified water levels (tabulated results in Appendix A-4) was plotted against 11 different water levels. DUNERULE only models for water levels above the mean sea level; thus, no DUNERULE results were obtained for water levels between -1m and -5m to mean sea level. The graphs are provided in Figure 6-11a to Figure 6-11c.

For Wave Case 1 (calm conditions), both SBEACH and XBEACH showed no significant sensitivity to water level variation. SBEACH indicated nearly the same shoreline recession of the specified water level for all the different water levels without any clear linear increase or decrease as the water level increased. The XBEACH results were less constant, but still not indicative of sensitivity to water level variation. XBEACH showed recession values that were in the region of 1m onshore, where SBEACH showed values five times larger than the XBEACH values. DUNERULE exhibited extreme sensitivity to water level variation with a near linear increase in shoreline recession as the water levels were increased.

For Wave Case 2 and Wave Case 3 the same lack of sensitivity was shown in SBEACH and XBEACH as in Wave Case 1. The shoreline recession values remained constant for SBEACH and XBEACH for all the different water level elevations. It was noted that the SBEACH shoreline recession values not only remained the same for different water levels of a wave condition, but it also remained almost the same for all of the three wave cases. In Wave Case 1, the shoreline recession averaged 4.9m, in Wave Case 2, the shoreline recession averaged 5.7m and in Wave Case 3, the shoreline recession averaged 5.4m for the different water level elevations. The erosion volumes did however differ and it was assumed that this outcome was coincidently achieved for the selected wave conditions. The averaged shoreline recession for the different water levels increased from 1m to 50.3m for Wave Case 1 to Wave Case 3 in XBEACH.





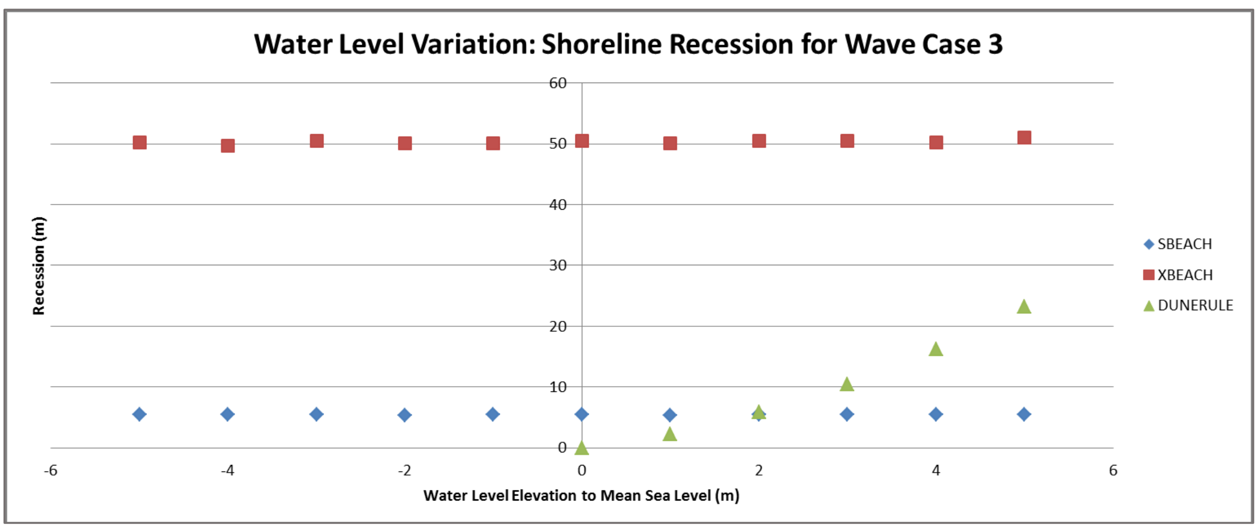


Figure 6-11: Shoreline Recession due to Water Level Variation for (a) Wave Case 1, (b) Wave Case 2 and (c) Wave Case 3

DUNERULE, on the other hand, showed clear sensitivity to water level variation when the shoreline recession was analysed. For all of the three wave conditions, the shoreline recession increased as the water level increased, following a second order polynomial trend. DUNERULE is a model that is based on a specific base study. All the output parameters are calculated in relation to the original base study results. The increase in shoreline recession is a function of $\left(\frac{x}{5}\right)^{1/3}$ (where x is the specified water level to mean sea level), which explains why a large increase in eroded volumes above the water level occurs when the sea level is increased.

6.3 Storm Duration

6.3.1 Overview of Model Sensitivity Analysis to Storm Duration

Thirty model cases were analysed in each of the three models: SBEACH, XBEACH and DUNERULE. The outcomes of all 30 cases were successfully obtained for each model without exceptions.

Figure 6-12 and Figure 6-13 show the initial and final cross-shore beach profiles as generated by SBEACH and XBEACH respectively for a randomly selected case, Run 2.15. The output of the DUNERULE model for the same run, was a dune erosion volume of 65.20m^3/m and a dune recession of 5.43m after 96-hour impact. The initial and final beach profiles for all the SBEACH and XBEACH cases as well as the DUNERULE results are provided in Appendix B-3.

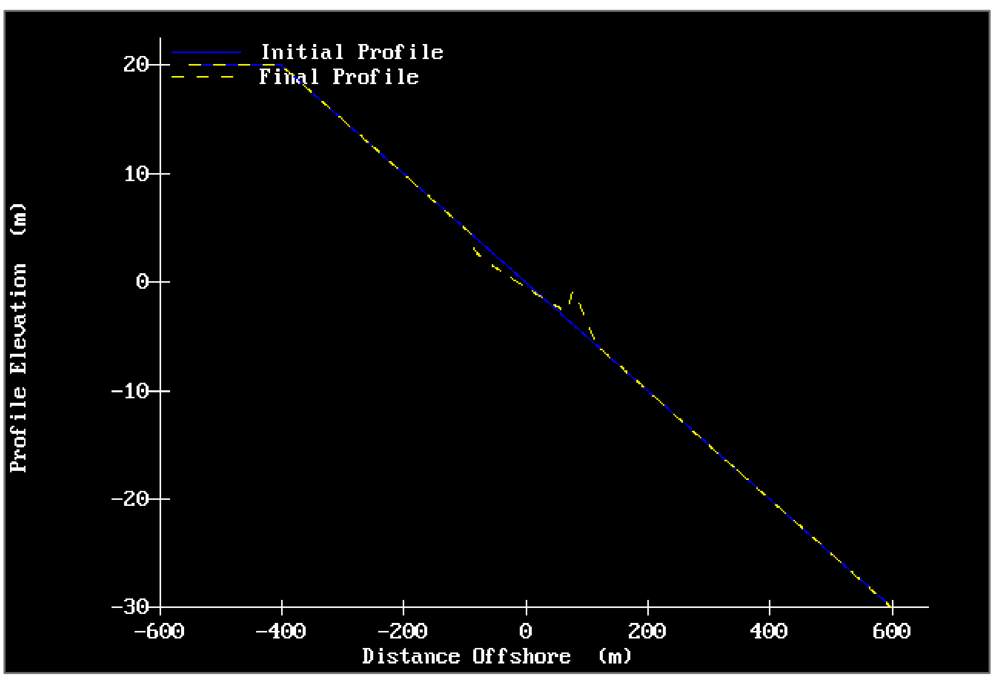


Figure 6-12: Storm Duration - Initial and Final Beach Profiles of Run 2.15 for SBEACH

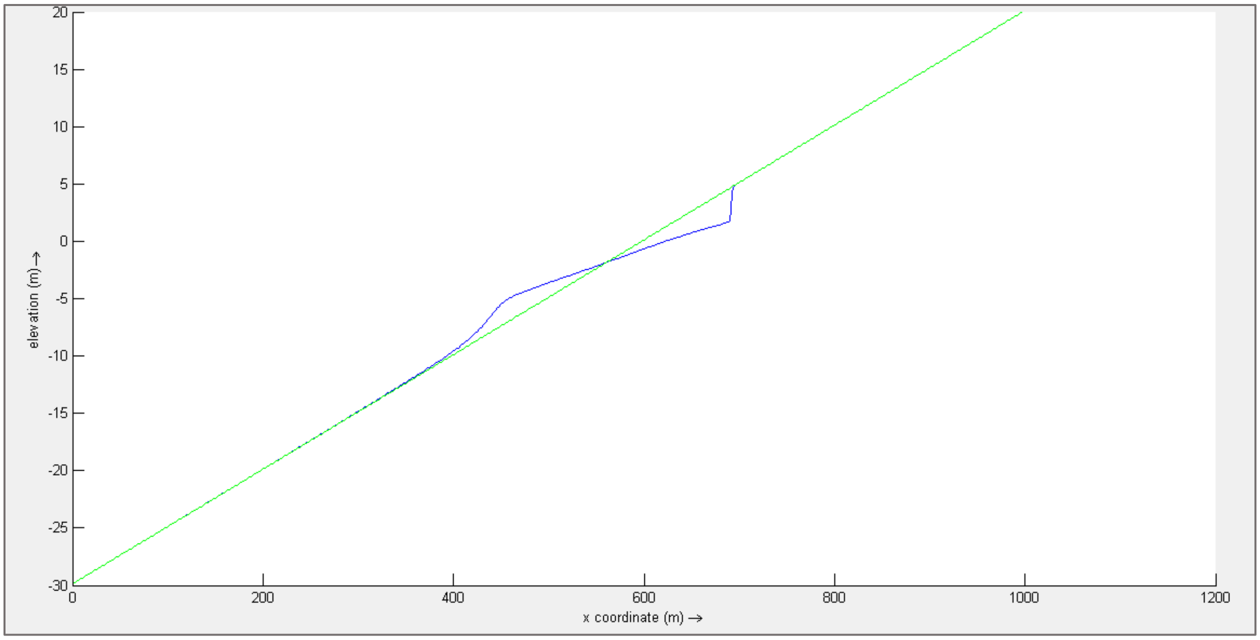
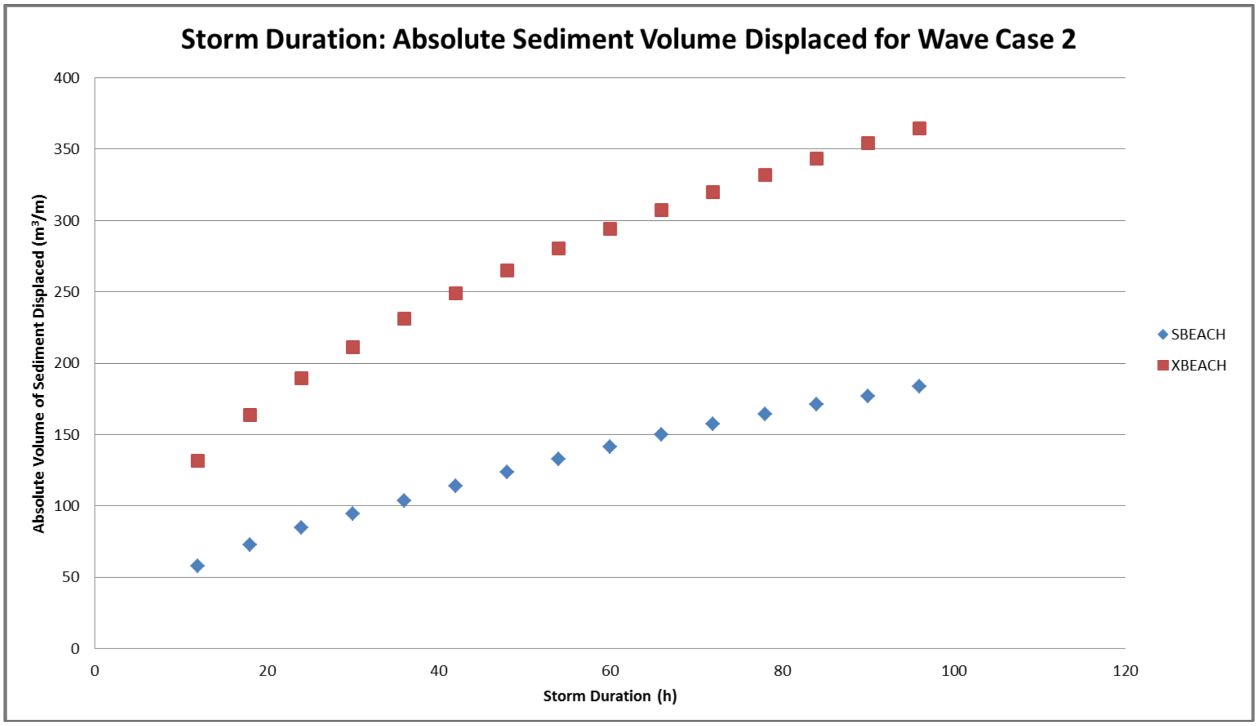


Figure 6-13: Storm Duration - Initial and Final Beach Profiles of Run 2.15 for XBEACH

6.3.2 Absolute Volume of Sediment Displaced

In order to analyse the sensitivity of the different numerical models to storm duration, the absolute volume of sediment displaced was calculated for 15 different water levels under two different wave conditions using different numerical models. Since DUNERULE does not provide enough information in its output to derive the absolute volume of sediment displaced, only the sensitivity of SBEACH and XBEACH to storm duration were studied by analysing the absolute sediment transport volumes. For each wave condition (Case 2 and Case 3), the absolute volume of displaced sediment volumes (tables in Appendix B-4) were plotted against 15 different water levels. These graphs are provided in Figure 6-14a and Figure 6-14b.



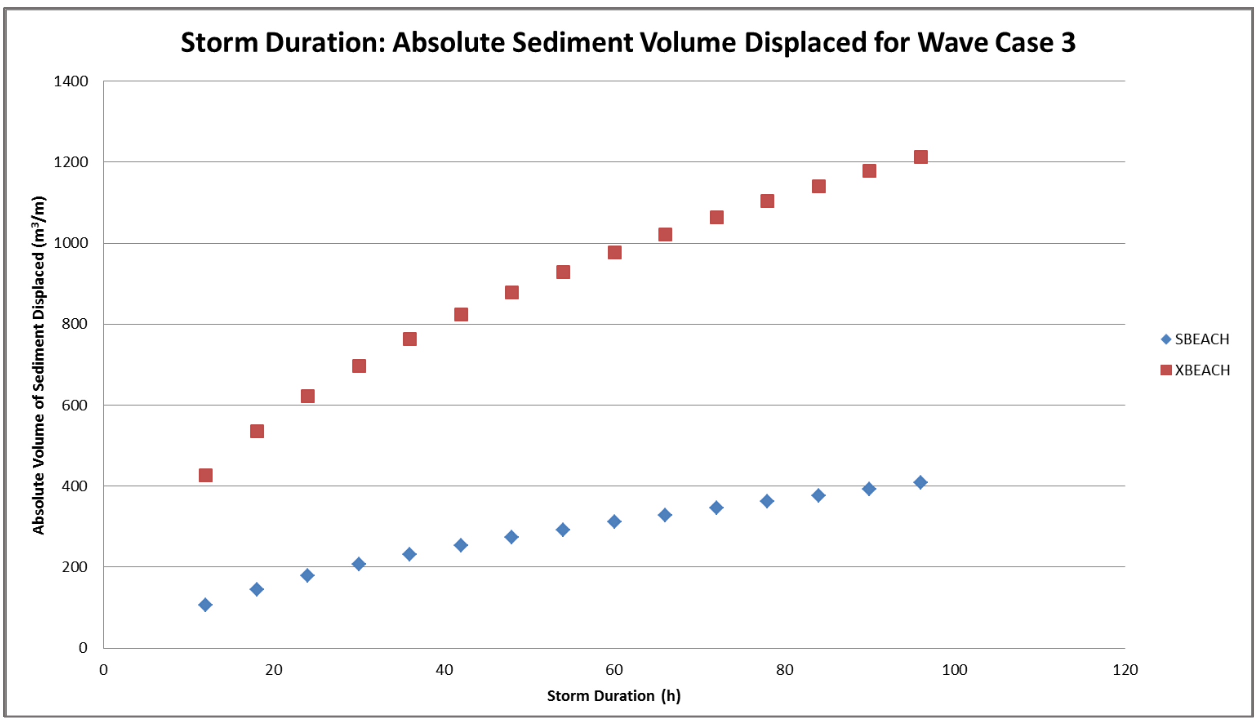


Figure 6-14: Absolute Sediment Volume Displaced due to Storm Duration for (a) Wave Case 2 and (b) Wave Case 3

For Wave Case 2, both SBEACH and XBEACH showed sensitivity to storm duration when the absolute displaced sediment volumes were compared. SBEACH and XBEACH showed an increase in absolute displaced sediment volumes as the storm durations grew longer. It was, however, observed that the rate at which the displaced sediment volumes increased, decreased for storms with longer durations. In other words, for a twelve-hour storm, the average amount of sediment displaced per hour was larger than the average amount of sediment displaced per hour for storms with durations longer than 12 hours. The XBEACH values of absolute displaced sediment volumes were higher than the SBEACH results.

XBEACH and SBEACH behaved similarly in the predictions of the absolute displaced sediment volumes in Wave Case 3 as in Wave Case 2. The observed absolute volumes of sediment displacement were, however, much larger than those observed for the mild storm conditions of Wave Case 2.

The observation that the absolute displaced sediment volume is larger for a longer storm duration, agrees with what was expected. Storms generally cause erosion of cross-shore beach profiles, since more energy is brought to the shore during storms than during calmer conditions prior to storms. An increase in energy will cause an increase in sediment transport and in erosive conditions, an increase in offshore sediment transport. The increase in energy explains why the beach profiles started to erode in both models for both wave cases. According to the theory of equilibrium beach profiles (discussed in Section 2.3), a beach profile will continue to change under new wave conditions, until an equilibrium beach profile is reached. The rate of sediment transport will theoretically decrease as a storm progresses, since the wave energy impact will become less significant as the beach approaches an equilibrium profile for the specific wave conditions.

From the results it appeared that none of the modelled storm durations were long enough for the beach profile to reach an equilibrium position, but the average amount of sediment displaced per hour decreased as storm durations grew longer. The longer modelled storm durations had a smaller averaged displaced sediment volume per hour, since the beach profiles were closer to an equilibrium position.

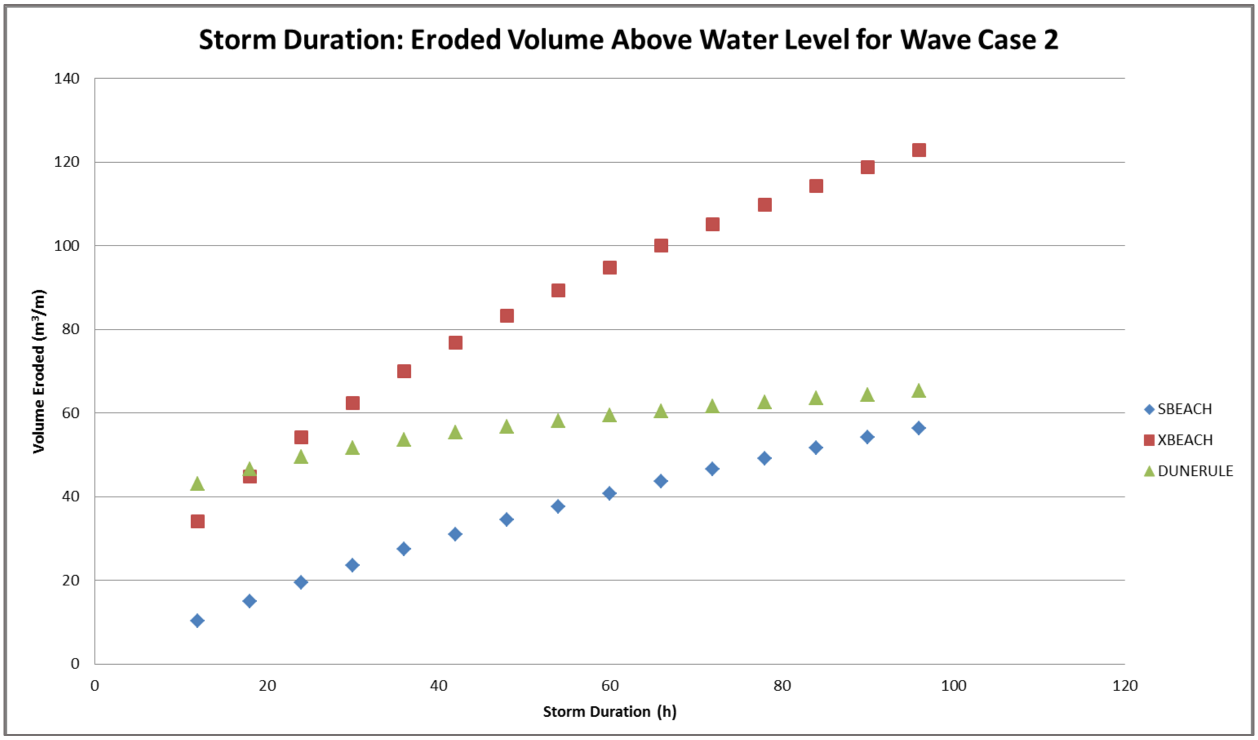
6.3.3 Eroded Volume of Sediment above Water Level

The eroded volume of sediment above the specified water levels for the different model runs were analysed, since it is more representative of the area where damage to structures above the water level might occur. In order to analyse the sensitivity of the different numerical models to storm duration, the total volume of sediment eroded above the specified water levels was calculated. All three models provided output that was sufficient to determine the eroded volume of sediment above the water level. For each wave condition (Case 2 and Case 3), the eroded volume of sediment above the specified water levels (tabulated results in Appendix B-4) were plotted against 15 different storm durations. The graphs are provided in Figure 6-15a and Figure 6-15b.

All three models (SBEACH, XBEACH and DUNERULE) showed sensitivity to storm duration when the eroded volumes of sediment above the specified water levels were analysed. In Wave Case 2, all three models showed an increase in sediment volumes eroded above the water level as the storm durations increased. As with the absolute volume of sediment displacement, the average rate of erosion above the sea level decreased for longer storms. DUNERULE showed the least sensitivity towards storm duration and XBEACH showed the most sensitivity. The SBEACH average rate of eroded volume decreased with an increase in storm duration was less obvious than for SBEACH and DUNERULE.

In Wave Case 3, the models showed a similar response to storm duration as in Wave Case 2. The eroded volumes above the specified water levels were larger than the eroded volumes in Wave Case 2.

The reason for the increase in eroded sediment volumes and the decrease in average rates of erosion, is that the beach profiles strive to reach an equilibrium position for the specific wave conditions. The amount of sediment erosion decreases as a profile gets closer to its equilibrium position over time. None of the model cases reached an equilibrium profile for any of the model runs used in this analysis.



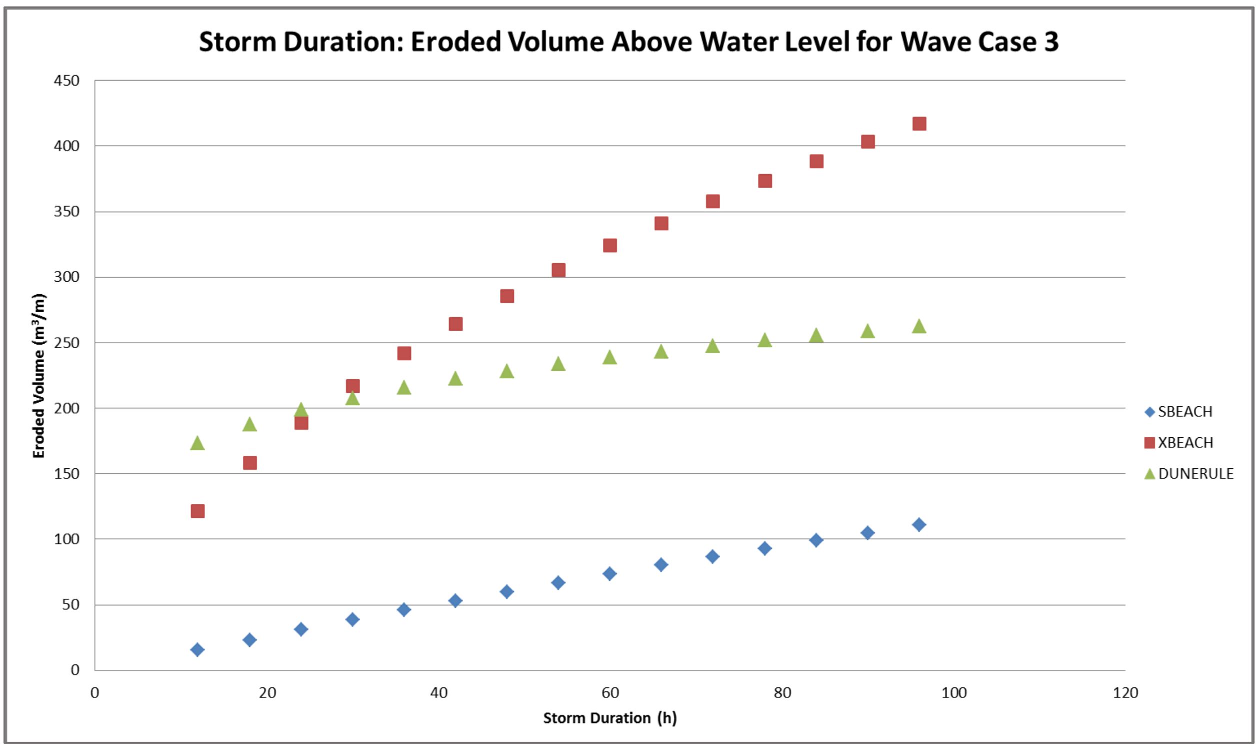


Figure 6-15: Transported Sediment Volumes Above Specified Water Levels due to Storm Duration for (a) Wave Case 2 and (b) Wave Case 3

6.3.4 Maximum Averaged Sediment Transport Rate

Another factor studied in order to analyse the sensitivity of the different numerical models to storm duration was the maximum averaged sediment transport rate For each wave condition (Case 2 and Case 3), the maximum averaged sediment transport rates (sediment transport rate distribution graphs provided in Appendix B-5) were plotted against 15 different storm durations. Negative sediment transport rates indicate offshore sediment transport. These graphs are provided in Figure 6-16a and Figure 6-16b.

In Wave Case 2, the transport rates for all the cases in SBEACH and XBEACH were in an offshore direction. The maximum averaged sediment transport rates decreased as storm durations increased, showing sensitivity of both SBEACH and XBEACH to storm duration. The reduction in maximum averaged sediment transport rates for longer storms, was more significant for XBEACH than for SBEACH.

The model cases in Wave Case 3 responded in a similar manner to storm duration increase as in Wave Case 2. The transport rate values were, however, higher.

Once again, the observations can be justified by referring to equilibrium beach profiles. The change in wave energy caused by storms instigates offshore sediment transport. The cumulative amount of sediment transported offshore is higher for storms with longer durations, but as already discussed in Section 6.3.2, the average rate of sediment transport decreases for longer storm durations due to profiles being closer to equilibrium states. At the position where the maximum sediment transport occurs, the sediment transport rate will also inevitably decrease for longer storm durations, explaining why the maximum sediment transport rates decreased for all the model cases.

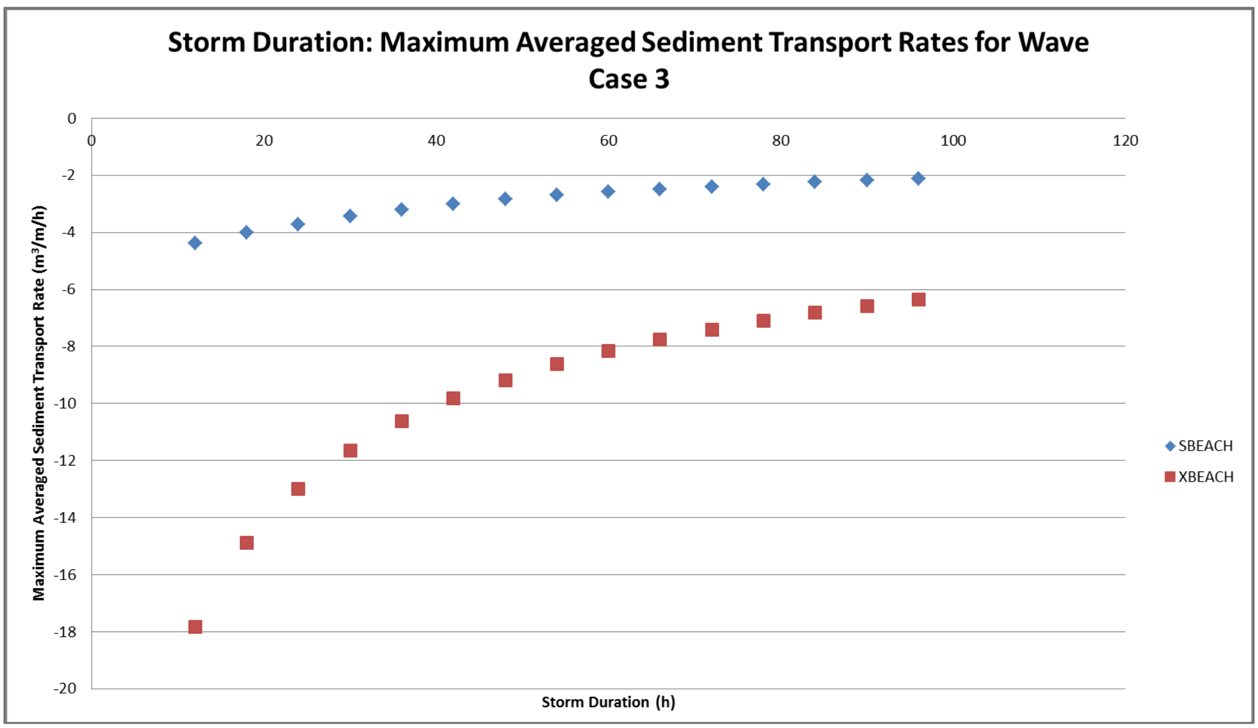


Figure 6-16: Maximum Averaged Sediment Transport Rates due to Storm Duration for (a) Wave Case 2 and (b) Wave Case 3

6.3.5 Position of Maximum Sediment Transport Rate

The only non-volumetric factor that was studied to analyse the sensitivity of the different numerical models to storm duration, was the position of the maximum averaged sediment transport rate. The position of the maximum averaged sediment transport rate was calculated for 15 different storm durations under three different wave conditions using different numerical models. Only the sensitivity of SBEACH and XBEACH to storm duration were studied (DUNERULE does not provide sediment transport rates as output) by analysing the position of the maximum averaged sediment transport rates. For each wave condition (Case 2 and Case 3), the position of the maximum averaged sediment transport rates (sediment transport rate distribution graphs provided in Appendix B-5) were plotted against 15 different storm durations. These graphs are provided in Figure 6-17a and Figure 6-17b.

In Wave Case 2 the position of the maximum sediment transport rates initially shifted offshore as the storm durations increased from 12 to 36 hours in SBEACH. For storm durations longer than 36 hours, the position of the maximum sediment transport rates shifted landward as the storm durations increased. XBEACH behaved significantly different from SBEACH, since the offshore distance where the maximum sediment transport rates occurred, increased as the storm durations increased. Even with the different reactions of the position of the maximum sediment transport rate of SBEACH and XBEACH towards storm duration, both models showed sensitivity to storm duration when the positions of maximum sediment transport rate were analysed.

SBEACH behaved slightly different for Wave Case 3, where the offshore distance at which the maximum sediment transport rates occurred, increased as the storm duration increased up to 84 hours. After 84 hours, the position of maximum sediment transport shifted landward for longer storm durations. XBEACH behaved the same in Wave Case 3 as in Wave Case 2.

No theoretical explanation could be found as to why the models behaved as they behaved in the study of the position of maximum sediment transport *versus* storm duration. SBEACH and XBEACH have different wave breaking and sediment transport approaches, explaining the differences in response to storm duration.

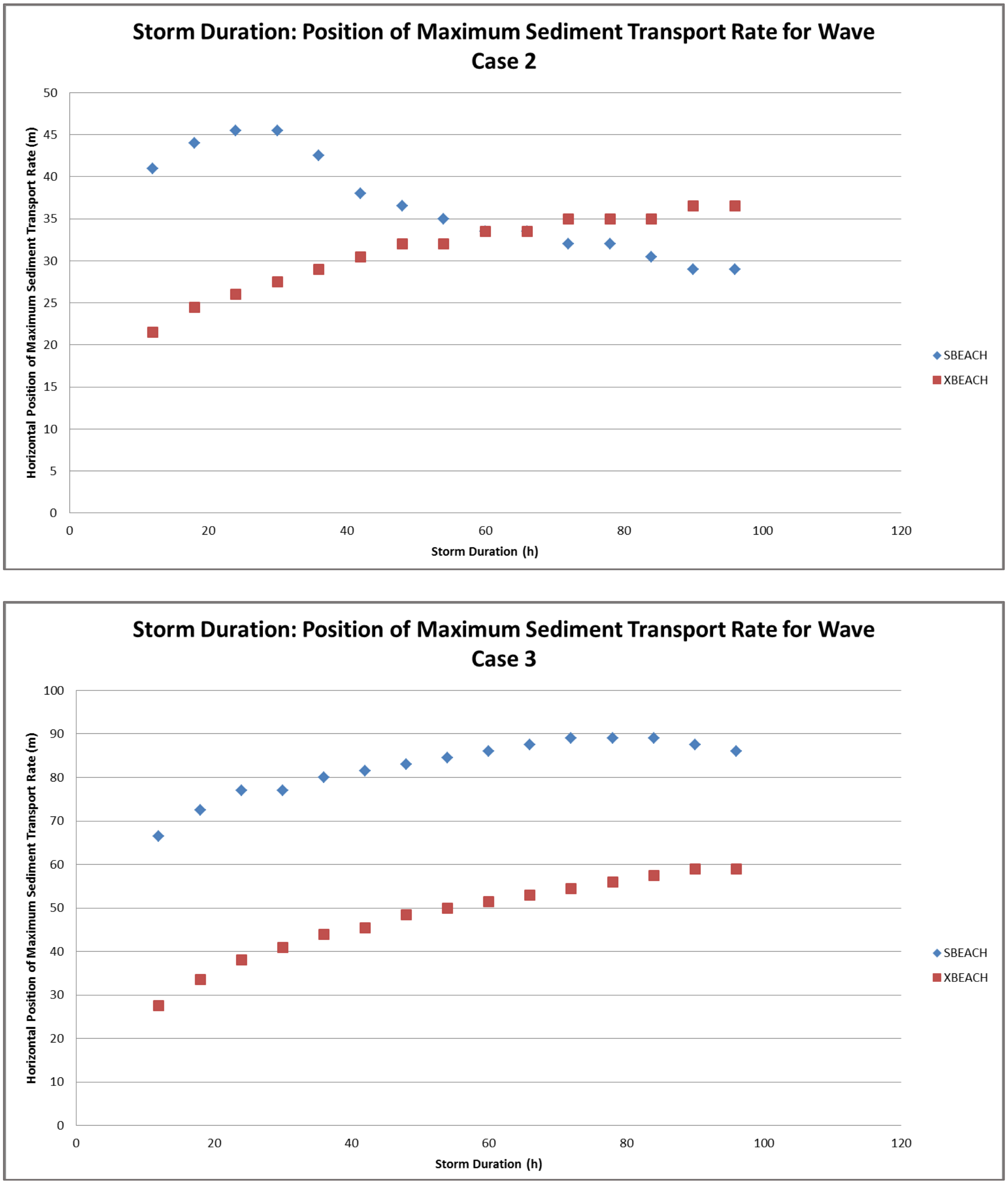


Figure 6-17: Position of Maximum Averaged Sediment Transport Rates due to Storm Duration for (a) Wave Case 2 and (b) Wave Case 3

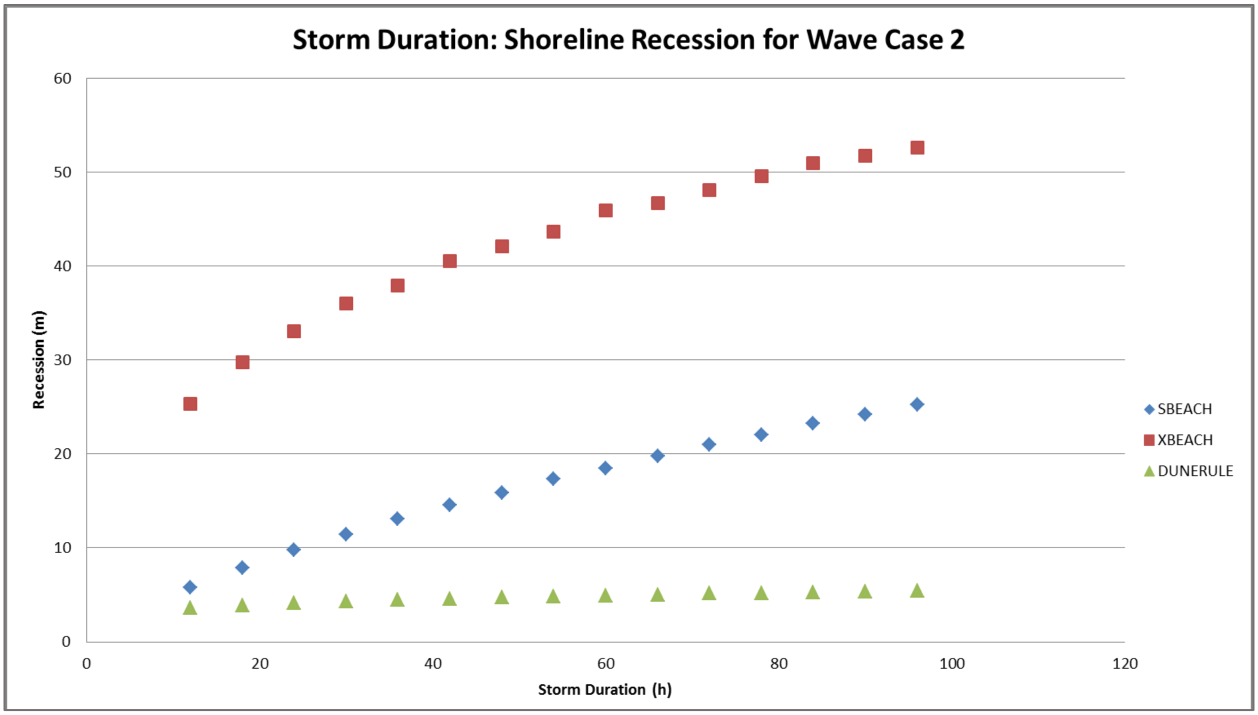
6.3.6 Recession of Shoreline

Since it is an important measure of the impact of the wave conditions, the recession of the shoreline at the specified water levels were calculated for 15 different storm durations under two different wave conditions. All three models provided output that was sufficient to determine the shoreline recession at the water level. For each wave condition (Case 2 and Case 3), the shoreline recession at the specified water levels (tabulated in Appendix B-4) were plotted against 15 different storm durations. The graphs are provided in Figure 6-18a and Figure 6-18b.

For Wave Case 2, DUNERULE, SBEACH and XBEACH showed sensitivity to storm duration when the recessions of the shorelines were compared. All three models showed an increase in shoreline recession as storm durations increased. The average rate at which the shorelines receded, however, decreased as the storm duration increased. The DUNERULE model showed very little difference between the recession of the shorelines. XBEACH showed the largest difference in shoreline recession between short and long storm durations.

The observations made for Wave Case 3 were similar to those made for Wave Case 2. It was, however, noticed that the recession of the SBEACH shorelines were the same for both wave conditions, even though the recessions were larger for the DUNERULE and XBEACH models in Wave Case 3.

The reason for the increase in shoreline recession and decrease in rate of shoreline recession with an increase in storm duration is explained through the theory of beach profile equilibrium. As already discussed, none of the storm durations in any of the models were long enough to result in equilibrium beach profiles. The beach profiles did, however, erode at smaller average rates for storms with longer durations, implying that the profiles for longer storms durations were closer to an equilibrium position than the profiles for shorter equilibrium conditions. No explanation could be found as to why the SBEACH results remained the same for both cases, except that it is one of the SBEACH model shortcomings.



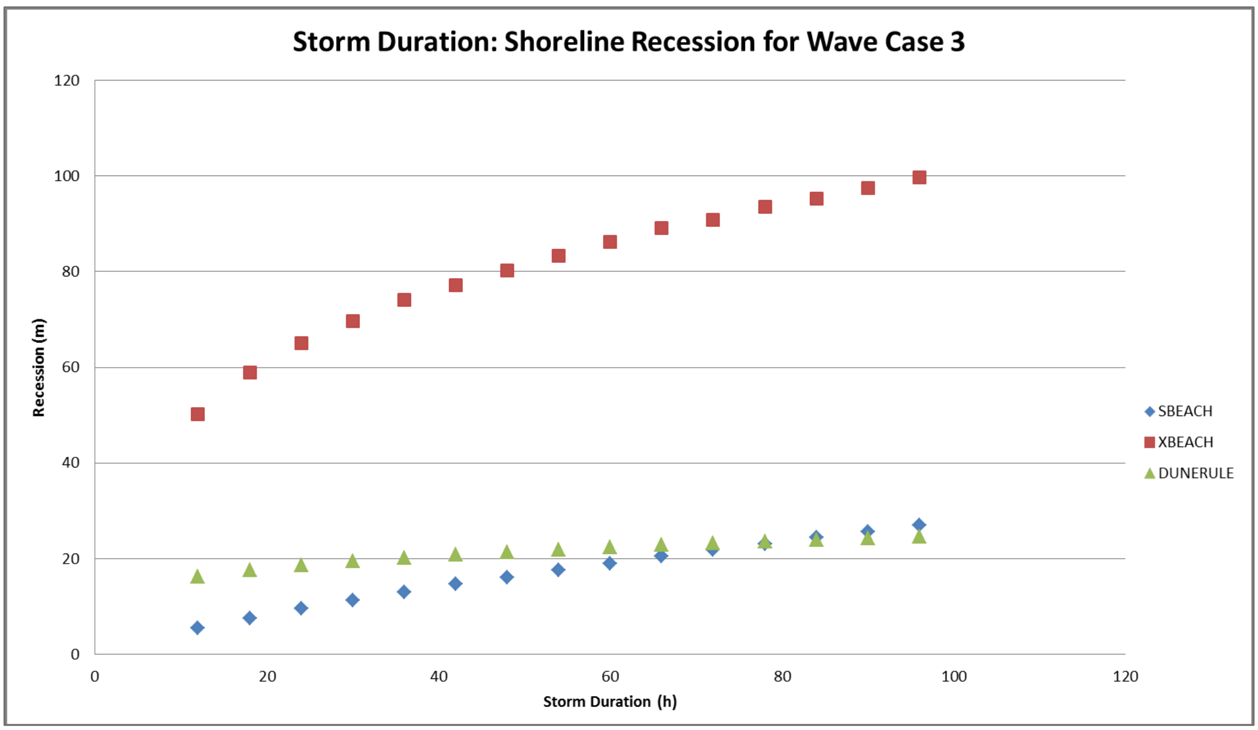


Figure 6-18: Shoreline Recession due to Storm Duration for (a) Wave Case 2 and (b) Wave Case 3

6.4 LONG WAVES

6.4.1 Overview of Model Sensitivity Analysis to Long Waves

Twelve free long wave model cases (F.1.1 to F.3.4) were analysed in both SBEACH and XBEACH. No free long wave sensitivity analysis was done using DUNERULE, since there was no possible method to add free long waves to the DUNERULE model. The outcomes of all 12 cases were successfully obtained for both SBEACH and XBEACH without exceptions.

Another twelve long wave model cases (B.1.2 to B.3.4) were analysed, but with the long waves being generated as a bound long wave due to bichromatic wave conditions. Only XBEACH had the capability of modelling bichromatic waves; thus, neither the sensitivity of SBEACH nor DUNERULE to bound long waves were analysed. The outcomes of all 12 cases were successfully obtained in XBEACH without exceptions.

Figure 6-19 and Figure 6-20 shows the initial and final cross-shore beach profiles as generated by SBEACH and XBEACH respectively for a random case, Run F.2.4. The initial and final beach profiles for all the SBEACH and XBEACH bound and free long wave sensitivity runs are provided in Appendix C-3.

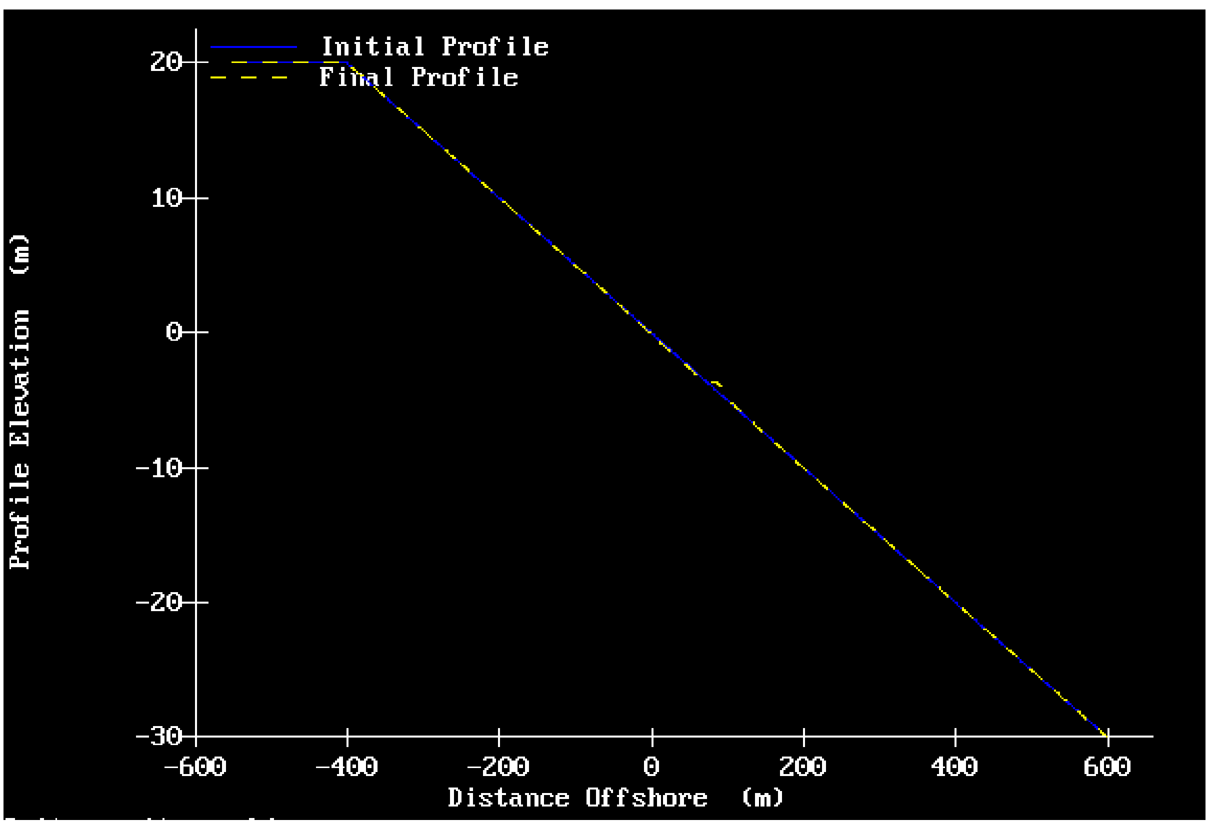


Figure 6-19: Long Wave - Initial and Final Beach Profiles of Run F.2.4 for SBEACH

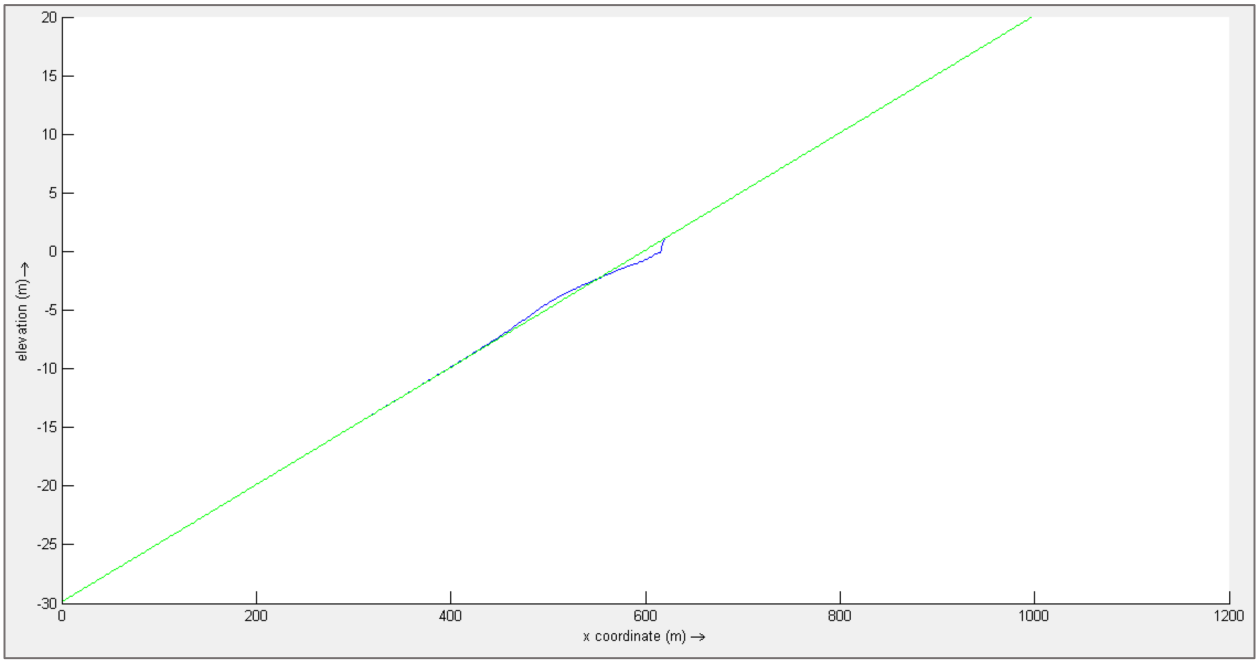


Figure 6-20: Long Wave - Initial and Final Beach Profiles of Run F.2.4 for XBEACH

6.4.2 Absolute Volume of Sediment Displaced

In order to analyse the sensitivity of the different numerical models to long waves, the absolute volume of sediment displaced was calculated for all the model runs. There were four model runs per wave condition, with the first of the four runs modelled without long waves. The sensitivity of the models to long waves was calculated as the percentage difference between the absolute volume of displaced sediment of the monochromatic model run and that of the long wave model runs. The absolute displaced sediment volumes for each model run is provided in Appendix C-4.

The sensitivity of the models was analysed for free and bound long waves. The free long waves were entered into the models (SBEACH and XBEACH) as water level variation over very short periods (30s to 200s). Table 6-4 and Table 6-5 provide the comparison between the monochromatic and combined the monochromatic and free wave model runs for SBEACH and XBEACH respectively.

The bound long waves were entered into XBEACH by defining root-mean-square short wave conditions and a governing bichromatic short wave envelope period. The short wave envelope periods varied from 30s to 200s per wave condition. Table 6-6 provides the comparison between the monochromatic and bichromatic model runs for XBEACH.

Table 6-4: Comparison between SBEACH Model Runs With and Without added Free Long Waves based on Absolute Displaced Sediment Volumes

Model Run	Absolute Volume of Displaced Sediment (m^3/m)		Percentage Difference (%)
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 7.03	8.37	119.06
F.1.3		8.33	118.49
F.1.4		8.31	118.21
F.2.2	F.2.1 26.03	26.79	102.92
F.2.3		26.70	102.57
F.2.4		26.70	102.57
F.3.2	F.3.1 41.54	39.42	94.90
F.3.3		39.35	94.73
F.3.4		39.30	94.61

Table 6-5: Comparison between XBEACH Model Runs With and Without added Free Long Waves based on Absolute Displaced Sediment Volumes

Model Run	Absolute Volume of Displaced Sediment (m^3/m)		Percentage Difference (%)
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 4.01	9.00	224.44
F.1.3		3.96	98.75
F.1.4		3.79	94.51
F.2.2	F.2.1 66.61	78.18	117.37
F.2.3		79.13	118.80
F.2.4		69.33	104.08
F.3.2	F.3.1 207.1	208.92	100.87
F.3.3		266.03	128.45
F.3.4		222.30	107.34

Table 6-6: Comparison between Monochromatic and Bichromatic XBEACH Model Runs based on Absolute Displaced Sediment Volumes

Model Run	Absolute Volume of Displaced Sediment (m^3/m)		Percentage Difference (%)
	Monochromatic	Bound Long Wave	
B.1.2	B.1.1 4.01	7.05	175.81
B.1.3		6.95	173.32
B.1.4		6.38	159.10
B.2.2	B.2.1 66.61	131.49	197.40
B.2.3		112.93	169.54
B.2.4		93.99	141.10
B.3.2	B.3.1 207.1	347.79	167.93
B.3.3		340.64	164.48
B.3.4		296.27	143.06

From Table 6-4 and Table 6-5, it is observed that SBEACH and XBEACH are sensitive to the effect of free long waves (modelled as water level variation) based on absolute displaced sediment volumes. However, the responses of SBEACH and XBEACH to the free long waves differ. SBEACH maintained a similar beach profile response for all three free long wave conditions per short wave condition. The difference in beach profile response for SBEACH was also much more significant for the shorter free long wave periods. XBEACH on the other hand showed no coherency in beach profile response due to increases in long wave period, but also showed a greater significant difference for short infra-gravity wave periods. XBEACH is sensitive to bound long waves forced by bichromatic wave conditions, with large differences between the beach profile responses to monochromatic and bichromatic wave conditions. Shorter long wave periods induced larger absolute displaced sediment volume differences than longer long wave periods.

6.4.3 Eroded Volume of Sediment above Water Level

The eroded volume of sediment above the specified water level (mean sea level) was calculated for all the model runs to determine whether the numerical models, SBEACH and XBEACH, are sensitive to long waves. The eroded volume of sediment above the water level was determined as described in Section 6.1.3.

The eroded volume of sediment above the water level for each model run is provided in Appendix C-4. Table 6-7 and Table 6-8 provide the comparison between the monochromatic and combined monochromatic and free wave model runs for SBEACH and XBEACH respectively. Table 6-9 provides the comparison between the monochromatic and bichromatic model runs for XBEACH.

Table 6-7: Comparison between SBEACH Model Runs With and Without added Free Long Waves based on Eroded Sediment Volumes Above the Water Level

Model Run	**Eroded Volume of Sediment (m^3/m)**		**Percentage Difference (%)**
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 1.27	1.09	85.83
F.1.3		1.29	101.57
F.1.4		1.47	115.75
F.2.2	F.2.1 3.46	3.37	97.40
F.2.3		3.53	102.02
F.2.4		3.73	107.80
F.3.2	F.3.1 5.25	4.98	94.86
F.3.3		4.97	94.67
F.3.4		5.34	101.7

Table 6-8: Comparison between XBEACH Model Runs With and Without added Free Long Waves based on Eroded Sediment Volumes Above the Water Level

Model Run	Eroded Volume of Sediment (m^3/m)		Percentage Difference (%)
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 0.14	0.80	571.43
F.1.3		0.69	492.86
F.1.4		0.92	657.14
F.2.2	F.2.1 14.90	21.52	144.43
F.2.3		17.22	115.57
F.2.4		17.58	117.99
F.3.2	F.3.1 55.45	67.66	122.02
F.3.3		57.42	103.55
F.3.4		59.20	106.76

Table 6-9: Comparison between Monochromatic and Bichromatic XBEACH Model Runs based on Eroded Sediment Volumes Above the Water Level

Model Run	Eroded Volume of Sediment (m^3/m)		Percentage Difference (%)
	Monochromatic	Bound Long Wave	
B.1.2	B.1.1 0.14	2.05	1464
B.1.3		1.68	1200
B.1.4		1.24	885.7
B.2.2	B.2.1 14.90	51.35	344.6
B.2.3		42.00	281.9
B.2.4		32.22	216.2
B.3.2	B.3.1 55.45	134.28	242.2
B.3.3		127.87	230.6
B.3.4		103.83	187.2

From Table 6-7 and Table 6-8, it was observed that a difference exists between the beach profile response of the monochromatic and combined monochromatic and long wave conditions based on eroded sediment volume above the water level. The respective responses of SBEACH and XBEACH is, however, completely different. SBEACH showed increases in the difference between the monochromatic and combined wave conditions as the long wave periods increased. XBEACH,on the other hand, showed no coherency in beach profile response due to increases in long wave period. XBEACH showed sensitivity to bound long waves forced by bichromatic wave conditions, with large differences between the beach profile responses of monochromatic *and* bichromatic wave conditions. Shorter long wave periods induced larger eroded volumes above the water level than longer long wave periods.

6.4.4 Maximum Averaged Sediment Transport Rate

In order to analyse the sensitivity of the different numerical models to long waves, the maximum sediment transport rates were calculated for all the model runs. The maximum sediment transport rate graphs are provided in Appendix C-5. Table 6-10 and Table 6-11 provides the comparison between the monochromatic and combined monochromatic and added free wave model runs for SBEACH and XBEACH respectively. Table 6-12 provides the comparison between the monochromatic and bichromatic model runs for XBEACH.

Table 6-10: Comparison between SBEACH Model Runs With and Without added Free Long Waves based on Maximum Sediment Transport Rate

Model Run	**Maximum Sediment Transport Rate ($m^3/m/h$)**		**Percentage Difference (%)**
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 -0.293	-0.289	98.63
F.1.3		-0.306	104.44
F.1.4		-0.302	103.07
F.2.2	F.2.1 -1.08	-1.08	100.00
F.2.3		-1.09	100.93
F.2.4		-1.11	102.78
F.3.2	F.3.1 -1.73	-1.60	92.49
F.3.3		-1.60	92.49
F.3.4		-1.63	94.22

Table 6-11: Comparison between XBEACH Model Runs With and Without added Free Long Waves based on Maximum Sediment Transport Rate

Model Run	Maximum Sediment Transport Rate ($m^3/m/h$)		Percentage Difference (%)
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 -0.164	-0.373	227.44
F.1.3		-0.163	99.39
F.1.4		-0.155	94.51
F.2.2	F.2.1 -2.77	-3.26	117.69
F.2.3		-3.29	118.77
F.2.4		-2.89	104.33
F.3.2	F.3.1 -8.64	-8.71	100.81
F.3.3		-11.10	128.47
F.3.4		-9.28	107.41

Table 6-12: Comparison between Monochromatic and Bichromatic XBEACH Model Runs based on Maximum Sediment Transport Rate

Model Run	Maximum Sediment Transport Rate ($m^3/m/h$)		Percentage Difference (%)
	Monochromatic	Bound Long Wave	
B.1.2	B.1.1 -0.164	-0.291	177.44
B.1.3		-0.287	175.00
B.1.4		-0.263	160.37
B.2.2	B.2.1 -2.77	-5.48	197.83
B.2.3		-4.70	169.68
B.2.4		-3.91	141.16
B.3.2	B.3.1 -8.64	-14.49	167.71
B.3.3		-14.20	164.35
B.3.4		-12.35	142.94

From Table 6-10 and Table 6-11, it was observed that the SBEACH and XBEACH beach profile responses are sensitive to free long wave conditions, based on the maximum sediment transport rates. There was, however, no relation between the SBEACH and XBEACH beach profile responses and increases in long wave period. XBEACH showed sensitivity to bound long waves forced by bichromatic wave conditions, with large differences between the beach profile responses to monochromatic and bichromatic wave conditions. In this case, shorter long wave periods induced larger maximum sediment transport rate differences than longer long wave periods.

6.4.5 Position of Maximum Sediment Transport Rate

In order to analyse the sensitivity of the different numerical models to long waves, the position of the maximum sediment transport rates were determined for all the model runs. The maximum sediment transport rate graphs are provided in Appendix C-5. Table 6-13 and Table 6-14 provide the comparison between the monochromatic and combined monochromatic and added free wave model runs for SBEACH and XBEACH respectively. Table 6-15 provides the comparison between the monochromatic and bichromatic model runs for XBEACH.

Table 6-13: Comparison between SBEACH Model Runs With and Without added Free Long Waves based on Maximum Sediment Transport Rate Position

Model Run	**Maximum Sediment Transport Rate Position (m)**		**Percentage Difference (%)**
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 21.5	21.5	100.0
F.1.3		21.5	100.0
F.1.4		21.5	100.0
F.2.2	F.2.1 74.0	75.5	102.0
F.2.3		75.5	102.0
F.2.4		75.5	102.0
F.3.2	F.3.1 140	141.5	101.07
F.3.3		141.5	101.07
F.3.4		141.5	101.07

Table 6-14: Comparison between XBEACH Model Runs With and Without added Free Long Waves based on Maximum Sediment Transport Rate Position

Model Run	**Maximum Sediment Transport Rate Position (m)**		**Percentage Difference (%)**
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 15.5	17	109.7
F.1.3		15.5	100.0
F.1.4		12.5	80.6
F.2.2	F.2.1 48.5	27.5	56.7
F.2.3		54.5	112.4
F.2.4		45.5	93.8
F.3.2	F.3.1 83.0	99.5	119.9
F.3.3		95	114.5
F.3.4		80	96.4

Table 6-15: Comparison between Monochromatic and Bichromatic XBEACH Model Runs based on Maximum Sediment Transport Rate Position

Model Run	**Maximum Sediment Transport Rate Position (m)**		**Percentage Difference (%)**
	Monochromatic	Bound Long Wave	
B.1.2	B.1.1 15.5	11.0	73.33
B.1.3		14.0	90.32
B.1.4		14.0	90.32
B.2.2	B.2.1 48.5	45.5	93.8
B.2.3		38.0	78.4
B.2.4		45.5	93.8
B.3.2	B.3.1 83.0	68.0	81.9
B.3.3		71.0	85.5
B.3.4		83.0	100

From Table 6-13 and Table 6-14, it is observed that a difference exists between the beach profile response of the monochromatic and combined monochromatic and long wave conditions based on the position of the maximum sediment transport rate. There was, however, no coherency in the SBEACH and XBEACH beach profile responses due to increases in long wave period. XBEACH showed sensitivity to bound long waves forced by bichromatic wave conditions, with large differences between the beach profile responses to monochromatic and bichromatic wave conditions.

6.4.6 Recession of Shoreline

In order to analyse the sensitivity of the different numerical models to long waves, the shoreline recessions were determined for all the model runs. There were four model runs per wave condition, with the first of the four runs modelled without long waves. The sensitivity of the models to long waves was calculated as the percentage difference between the shoreline recessions of the monochromatic model runs and the long wave model runs. The shoreline recession results are tabulated in Appendix C-4. Table 6-16 and Table 6-17 provide the comparison between the monochromatic and combined monochromatic and added free wave model runs for SBEACH and XBEACH respectively. Table 6-18 provides the comparison between the monochromatic and bichromatic model runs for XBEACH.

Table 6-16: Comparison between SBEACH Model Runs With and Without added Free Long Waves based on Shoreline Recession

Model Run	**Shoreline Recession (m)**		**Percentage Difference (%)**
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 2.63	2.77	105.3
F.1.3		2.77	105.3
F.1.4		2.77	105.3
F.2.2	F.2.1 2.25	2.44	108.4
F.2.3		2.44	108.4
F.2.4		2.44	108.4
F.3.2	F.3.1 2.06	2.01	97.6
F.3.3		2.01	97.6
F.3.4		2.01	97.6

Table 6-17: Comparison between XBEACH Model Runs With and Without added Free Long Waves based on Shoreline Recession

Model Run	Shoreline Recession (m)		Percentage Difference (%)
	Monochromatic	Added Free Long Wave	
F.1.2	F.1.1 0.735	2.75	374.2
F.1.3		2.97	404.1
F.1.4		4.13	562.9
F.2.2	F.2.1 14.75	15.95	108.1
F.2.3		16.38	111.1
F.2.4		17.93	121.56
F.3.2	F.3.1 32.50	31.95	98.3
F.3.3		30.38	93.48
F.3.4		31.74	97.66

Table 6-18: Comparison between Monochromatic and Bichromatic XBEACH Model Runs based on Shoreline Recession

Model Run	Shoreline Recession (m)		Percentage Difference (%)
	Monochromatic	Bound Long Wave	
B.1.2	B.1.1 0.735	5.84	794.56
B.1.3		4.64	631.29
B.1.4		3.41	463.95
B.2.2	B.2.1 14.75	27.47	186.24
B.2.3		23.42	158.78
B.2.4		21.10	143.05
B.3.2	B.3.1 32.50	37.14	114.28
B.3.3		38.02	116.98
B.3.4		33.76	103.88

From Table 6-16 and Table 6-17, it was observed that both SBEACH and XBEACH are sensitive to free long waves, based on the recession of the shorelines of the monochromatic and combined monochromatic and long wave conditions. The SBEACH results indicated that the beach profile response was different between the combined and monochromatic conditions, but not between the different long wave periods. There was, however, no coherency in the XBEACH beach profile response, due to increases in long wave period. Both SBEACH and XBEACH are sensitive to the effect of free long waves (modelled as water level variation) based on the shoreline recession. XBEACH showed sensitivity to bound long waves forced by bichromatic wave conditions, with large differences between the beach profile responses to monochromatic and bichromatic wave conditions.

6.5 Summary

The SBEACH and XBEACH numerical models showed sensitivity to water level variation, which was explained through the wave shoaling effect. The variation in the volumetric beach profile responses for different water levels were less than 10% between the highest and lowest water level (+5m to -5m to sea level) and thus very small. Based on the results of these model runs, it can be inferred that if a water level is modelled incorrectly in SBEACH or XBEACH the volumetric results will be less than 10% different than when they were modelled correctly. This implies that water level to mean sea level is not significant. DUNERULE on the other hand also showed sensitivity to water level variation, but the increase of the volumetric parameters with an increased water level elevation was much bigger than the results from SBEACH and XBEACH. DUNERULE thus showed significant volumetric sensitivity towards changing water level elevations as per model approach.

When the positions of maximum sediment transport rates were analysed for SBEACH and XBEACH, as expected, a linear shift of horizontal positions were observed. This linear relationship implies that SBEACH and XBEACH are significantly sensitive to water level variation when the position of sediment transport is under consideration. DUNERULE does not provide outputs in which the model sensitivity to water level variation, based on location of impact, can be analysed. Based on these findings, it was concluded that SBEACH, XBEACH and DUNERULE are sensitive to water level variation as a whole. DUNERULE is, however, restricted to fixed water levels above mean sea level and can, thus, only be used for scenarios where the water level remains above mean sea level for a significant amount of time.

Both SBEACH and XBEACH numerical models showed sensitivity to storm duration, which was explained through the equilibrium beach profile theory. The variation in the volumetric beach profile responses for storm durations were significant, implying that an error in the modelling of storm duration will lead to large differences between the correctly and incorrectly modelled beach profiles. DUNERULE also showed sensitivity to storm duration, but the increase of the volumetric parameters with an increased storm duration was smaller than the results from SBEACH and XBEACH. In summary, SBEACH, XBEACH and DUNERULE showed significant volumetric sensitivity towards storm durations.

Although the SBEACH and XBEACH models did not show a clear trend in the shift of position of sediment transport, both models still showed sensitivity to the effect of storm duration on the position of sediment transport. DUNERULE did not provide outputs in which the model sensitivity to storm duration, based on location of impact, can be analysed. DUNERULE cannot predict the effects of storm duration if the mean sea level is not identified or if the storm surge level is at mean sea level or lower.

Both SBEACH and XBEACH showed sensitivity to free long waves, modelled as water level variation. It appeared that SBEACH was mainly sensitive to the long wave height, since the effect of long waves with different periods under the same wave conditions was the same. The XBEACH results did not clearly indicate a correlation between beach profile response to long waves with different wave periods. XBEACH also showed sensitivity to bound long waves forced by bichromatic wave conditions. A correlation seems to exist between the bound long wave period and the difference in beach profile response.

Overall, it was concluded that DUNERULE was too sensitive, based on research (Section 2.6.2.2) that indicated that short term water level variations only cause a shift in the wave impact zone and not a general increase sediment transport. DUNERULE was specifically formulated to model dune recessions. In this study, the dunes were considered to be the planar extension of the beach face. Therefore, the DUNERULE model might provide accurate results when a dune (with a steeper incline than the beach face) is present. For planar beaches, SBEACH and XBEACH would probably model cross-shore beach profile change due to varying water levels that are more accurate.

All three models showed acceptable responses to different storm durations, but the difference between the DUNERULE setback responses to different storm durations might be too narrow. Although SBEACH and XBEACH exhibited large quantitative differences in beach profile response to storm durations, it was not possible to draw conclusions on which model would predict more accurate beach profile response to different storm durations. SBEACH had a more stable response to free long waves, modelled as water level variation, than XBEACH. Without data to compare the models with, it is not clear which model would predict the impact of free long waves on cross-shore beach profiles more accurately, or whether the modelling of free long waves as water level variation, is even an acceptable approach.

7 Assessment of Cross-Shore Numerical Model Accuracy

7.1 General Model Accuracy Assessment Procedure

7.1.1 Assessment of Final Cross-Shore Beach Profile Prediction

The accuracy of numerical model prediction of final beach profiles may be analysed based on statistics. Van Rijn *et al.* (2003) proposed that the Brier Skill Score (BSS) can be used to verify the accuracy of numerical models for morphological cases. The BSS value is used to determine how close a modelled beach profile lies to the actual beach profile.

$$BSS = 1 - \left[\frac{\langle |x_p - x_m|^2 \rangle}{\langle |x_b - x_m|^2 \rangle}\right] \tag{6.1}$$

Where,

- BSS is the Brier Skill Score
- x_p is the calculated final beach profile depth at a distance from the shoreline (m)
- x_m is the measured final beach profile depth at a distance from the shoreline (m)
- x_b is the measured initial beach profile depth at a distance from the shoreline (m)

The BSS value indicates how well the model predicted the beach profile change. Table 7-1 indicates what accuracy certain intervals of BSS values represent.

Table 7-1: Qualification of error ranges of BSS parameter (Van Rijn *et al.*, 2003)

Qualification	BSS
Excellent	1.0-0.8
Good	0.8-0.6
Reasonable/Fair	0.6-0.3
Poor	0.3-0
Bad	<0

The BSS has a limitation, since it does not account for the migration direction of sand bars (Van Rijn *et al.*, 2003). In simpler terms, if the size of the modelled sand bar is small and correct, but at the wrong location, a better BSS value might be achieved than if the sand bar is at the correct location, but modelled too big.

This type of analysis is also only applicable to models where beach profile outputs are provided. Therefore, only the accuracy of SBEACH and XBEACH (not DUNERULE) in predicting final cross-shore beach profiles was verified using the BSS.

7.1.2 Assessment of Volumetric Cross-Shore Beach Profile Response

A volumetric property that can be obtained from SBEACH, XBEACH and DUNERULE output is the volume of eroded sediment above the specified sea level. This property is the most important volumetric property, since it directly relates to the impact that wave conditions will have on structures near the shoreline. The modelled volume of eroded sediment above the water level was thus compared to the measured volume of eroded sediment above the water level in order to determine the percentage accuracy of the volumetric model prediction. This process is schematised in Figure 7-1. The process to determine the volume of eroded sediment above the water level based on an initial and final profile is discussed in Section 6.1.3.

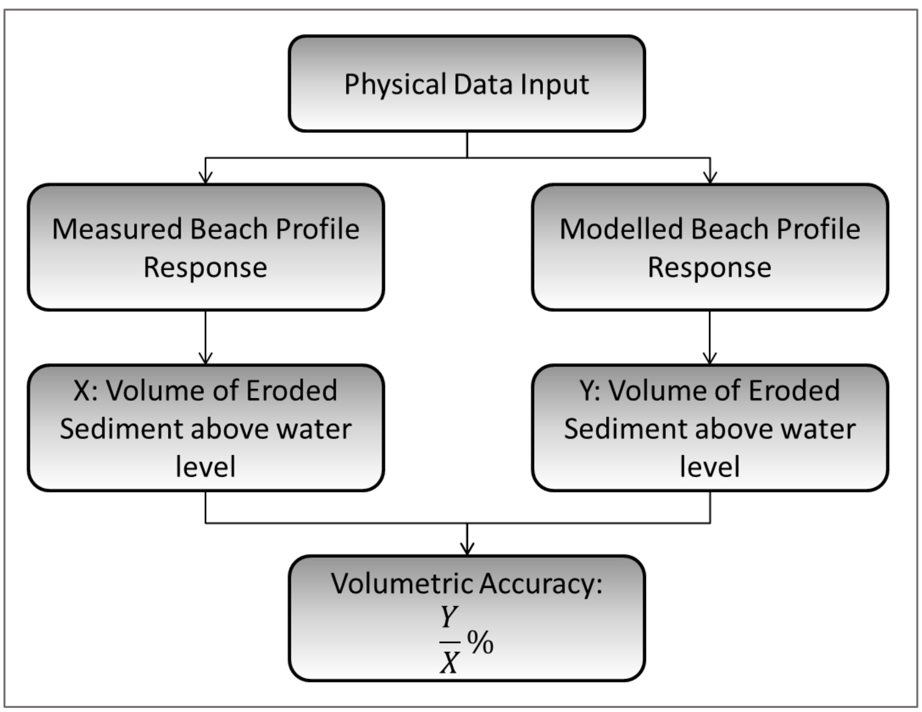


Figure 7-1: Process to Verify Volumetric Accuracy of Modelled Beach Profile Response

As part of the volumetric response study, the recession of the shoreline at water level was also analysed. Although this property is not strictly volumetric it was considered an important property of beach profile response necessary to be accurately predicted for construction or rehabilitation projects near the shoreline. The process to verify the accuracy of the models in predicting shoreline recession was the same as the process described in Figure 7-1. The process to predict the shoreline recession is discussed in Section 6.1.6.

7.1.3 Visual Analysis

A visual analysis was done by comparing all the final profiles from the measured physical data to the modelled final profiles. The location and size of bars and steps and similar beach formations were compared visually between the measured and modelled profiles. This analysis was only applied to the SBEACH and XBEACH numerical models, since DUNERULE does not use initial profiles as input or provide final profiles as output.

7.2 Accuracy of Model Response Prediction of Beach Profile due to Water Level Variation

7.2.1 Assessment of Final Cross-Shore Beach Profile Prediction

The assessment of the final cross-shore beach profiles that were predicted by SBEACH and XBEACH, under varying water level conditions, was done by determining the Brier Skill Scores for all 23 cases that were modelled. The Brier Skill Score results for all the runs are provided in Appendix D-5. In Table 7-2, the Brier Skill Scores that were determined in both SBEACH and XBEACH are summarized through the identification of the amount of model cases that obtained different BSS qualifications (see Table 7-1).

Table 7-2: Summary of SBEACH and XBEACH Brier Skill Score Predictions for Varying Water Level Model Cases

BSS Qualification	SBEACH	XBEACH
Excellent	1	0
Good	4	1
Reasonable/Fair	6	5
Poor	6	6
Bad	6	11
Total	23	23

From Table 7-2 it is clear that SBEACH predicted final beach profile responses that statistically fitted the measured beach profile responses better than XBEACH. Nearly 50% of the SBEACH predictions qualified as reasonable to excellent predictions, where only 25% of the XBEACH predictions obtained the same qualifications. It was observed that SBEACH and XBEACH generally provided less accurate final profile predictions for cases where accretion occurred above the still water level. It did not appear that the accuracy of the model predictions specifically differed based on the duration of the model runs.

One possible explanation for the poor Brier Skill Scores obtained with the XBEACH model, was that the berms or offshore sandbars were either positioned incorrectly or not modelled at all. Through visual analysis (Section 7.2.3) a clearer reason for the poor final profile predictions of XBEACH in terms of the Brier Skill Scores might be obtained.

Based on the Brier Skill Scores, SBEACH is the more accurate model choice for prediction of beach profile response to varying water levels. DUNERULE was not included as part of the analysis, since it lacks the ability to predict beach profile response under varying water levels.

7.2.2 Assessment of Volumetric Cross-Shore Beach Profile Response

The volumetric cross-shore beach profile responses were determined by calculating the modelled volume of sediment eroded or accreted above the still water level and comparing it to the measured volumes. For the sake of consistency, the overall still water level from Case 911 was chosen as the reference point for the volume calculations. The results of the volumetric comparisons between the measured and modelled beach profile responses are provided in Appendix D-5. The results were summarised through the identification of the amount of modelled responses that fell in certain percentage brackets from the measured beach profile responses. The summary of the results is provided in Table 7-3.

Table 7-3: Percentage Difference between Modelled and Measured Volumetric Beach Profile Reponses in SBEACH and XBEACH

Percentage Bracket	SBEACH	XBEACH
0 - 10%	0	1
10 - 20%	1	2
20 - 50%	0	3
50 - 100%	4	5
100% +	18	12

From the results of the SBEACH and XBEACH modelled eroded or accreted volumes above the still water level, it was clear that neither SBEACH nor XBEACH consistently predicted beach profile response under different varying water level conditions. Although XBEACH predicted results that were more accurate than the SBEACH results, the XBEACH results on its own were not accurate within reasonable limits: 50% of the XBEACH results were more than 100% off from the actual measured volumetric beach profile responses.

From the results, there was no clear indication that the duration or pattern of water level variation influenced the accuracy of the results. In all the scenarios where the cumulative volume of sediment transported above the sea level was accretive, both SBEACH and XBEACH predicted erosion. This indicates that both SBEACH and XBEACH lack the ability to predict accretive scenarios properly.

The poor accretion results predicted by SBEACH are blamed on the empirical predictor that is used in SBEACH to determine the direction of sediment transport. This predictor has been under scrutiny by various researchers (see Section 5.2.1). A possible explanation as to why the XBEACH predictions of accretive scenarios were inaccurate, is that long waves and mean currents are not present in the CERC Large Wave Tank Case 911. The focus of XBEACH is that significant sediment transport is rather induced by long waves and mean currents than by monochromatic short waves. Therefore, the model is probably not well formulated to predict beach profile response under monochromatic wave conditions.

The horizontal shift of the still water level elevation was used to calculate the shoreline recession. The shoreline recessions calculated for Run 1 to Run 23 using SBEACH and XBEACH are tabulated in Appendix D-5. The results were analysed in a similar manner as the eroded volumes above the water level. Table 7-4 indicates how many model runs predicted shoreline recessions within certain percentage groups from the measured shoreline recessions.

The shoreline recession results differed from the eroded volume results, since the SBEACH results are slightly more accurate than the XBEACH results. Both SBEACH and XBEACH also predicted the shoreline recessions better than they predicted the eroded volume of sediment above the still water level.

Table 7-4: Percentage Difference between Modelled and Measured Shoreline Recessions in SBEACH and XBEACH

Percentage Bracket	SBEACH	XBEACH
0 - 10%	3	0
10 - 20%	2	2
20 - 50%	2	6
50 - 100%	9	7
100% +	7	8

As a whole, based on the volumetric and setback results, it is recommended to use XBEACH when predicting cross-shore beach profile response under varying water levels. It should be kept in mind that these models (SBEACH and XBEACH) were calibrated based on two available measured profiles and that calibration profiles are not always available in practice. So even though the accuracy of the XBEACH results may be improved through extensive calibration (and not just through the calibration of four parameters as in this study), it is likely that surveyed profiles are not available for comparison and the accuracy of the results will decrease. It is possible that the XBEACH results will also be more accurate under random wave conditions, since long waves are then included, but further research will have to be done to confirm this hypothesis.

7.2.3 Visual Analysis

All the SBEACH and XBEACH initial and final (measured and modelled) profiles for the 23 cases studied to assess the water level variation impact on cross-shore sediment transport are provided in Appendix D-6. In Case 911 it was observed that an offshore bar developed and moved slightly landward as the water level increased. This was explained through the shift of the wave breaking point to a more landward position. With a decrease in water levels, the offshore bar migrated in an offshore direction because the breaking point shifted offshore. After the first rise and fall of the water level, the following rise in water level caused the formation of a secondary offshore bar landward of the main offshore bar. The explanation for this is that the height of the main offshore bar was lower than the breaking point of the waves in higher water levels and the waves thus passed over the offshore bar without causing significant changes. When the waves reached their breaking point landward of the main offshore bar, a secondary bar was formed.

Figure 7-2 shows the plots of the initial and final (measured and modelled) profiles of Run 23 that was modelled over 40.3 hours in SBEACH and XBEACH respectively. This figure is representative of the general visual observations.

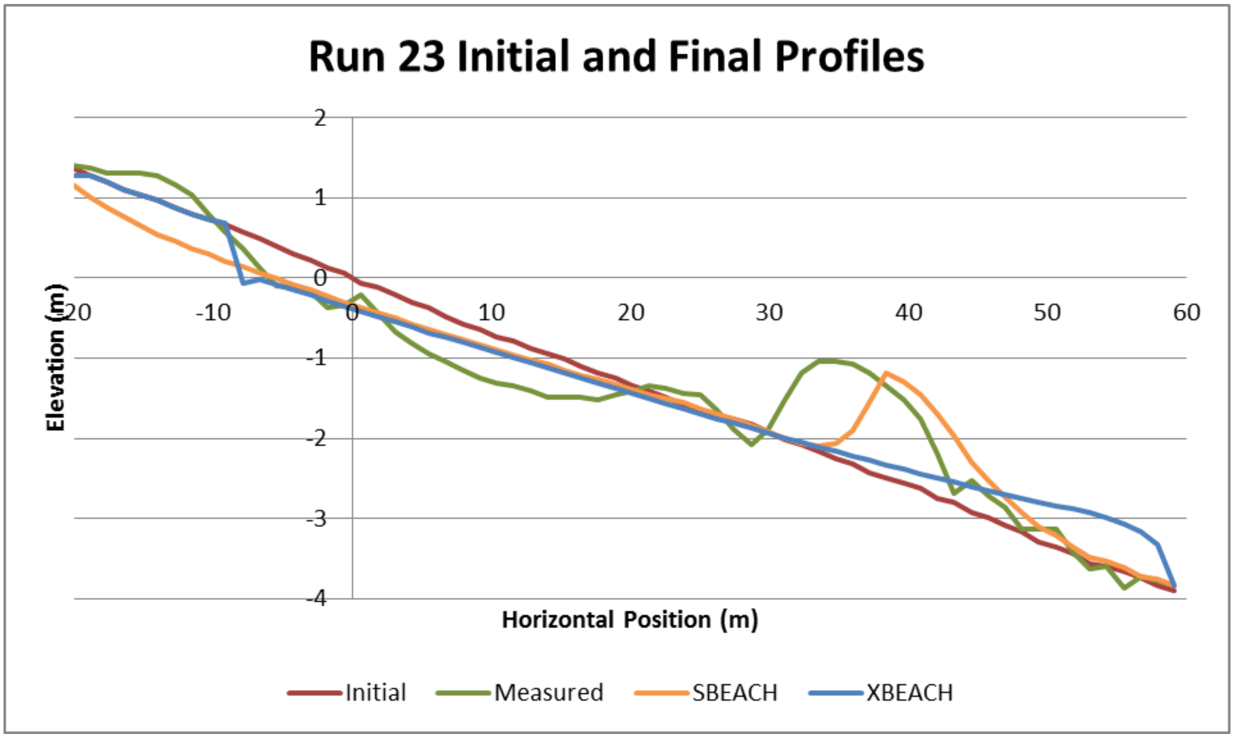


Figure 7-2: Measured and Modelled Beach Profile Responses under Varying Water Levels

Generally, the observed final profiles modelled by SBEACH appeared to be representative of the measured beach profile responses. In most of the measured cases, the beach accreted toward the top of the beach face, even though the area directly above the still water level eroded. The SBEACH model results did not predict this accretion in any of the runs. The poorly formulated SBEACH sediment transport predictor is probably the reason for the inaccurate accretion predictions in SBEACH. The representative beach slope between the still water level and the main offshore bar was well predicted in SBEACH. It was noticed that no secondary offshore bars were predicted in SBEACH. This observation was expected, since, as explained in Section 5.2.1, SBEACH was formulated to only predict one offshore bar. The main offshore sand bar was often modelled slightly too landward or seaward of the surveyed offshore bar. The height of the offshore bar was well predicted throughout all the modelled runs, but the volume of the bar was often under predicted.

The XBEACH results were visually not representative of the measured beach profiles. No offshore sand bars were predicted in any of the runs. It is possible that the lack of long waves and mean currents contributed to the poor profile predictions, since long waves and mean currents are the main driving forces of sediment transport in XBEACH (Deltares, 2015).

It was observed that XBEACH predicted the erosion and accretion above the water level relatively well compared to SBEACH. Although the accretion at the top of the beach face was not modelled, no erosion was observed in these areas either, explaining why the eroded volumes above the water level was better predicted with XBEACH.

Based on these visual observations, SBEACH is the model of choice to predict cross-shore beach profile response under varying water levels. It is, however, possible to improve the XBEACH results through extensive calibration. In the field, the XBEACH results may also prove to be more accurate since long waves and mean currents are then included in the surf zone hydrodynamics.

7.3 Accuracy of Model Response Prediction of Beach Profile due to Storm Duration

7.3.1 Assessment of Final Cross-Shore Beach Profile Prediction

The Brier Skill Scores were determined for all the different storm durations under all five erosional cases that were analysed. Only the Brier Skill scores for the SBEACH and XBEACH beach profile responses were determined, since DUNERULE does not have a final profile output that can be compared to the measured beach profile response.

The Brier Skill Scores for the XBEACH and SBEACH models were plotted for the storms with different durations. All BSS values that were less than zero (and therefore indicated a bad fit between the measured and calculated profiles) were set to a value of 0.1 for plotting purposes. A table with the complete Brier Skill Score analysis results is provided in Appendix E-5. The plots comparing the BSS values of both SBEACH and XBEACH for the different modelled cases are shown in Figure 7-2.

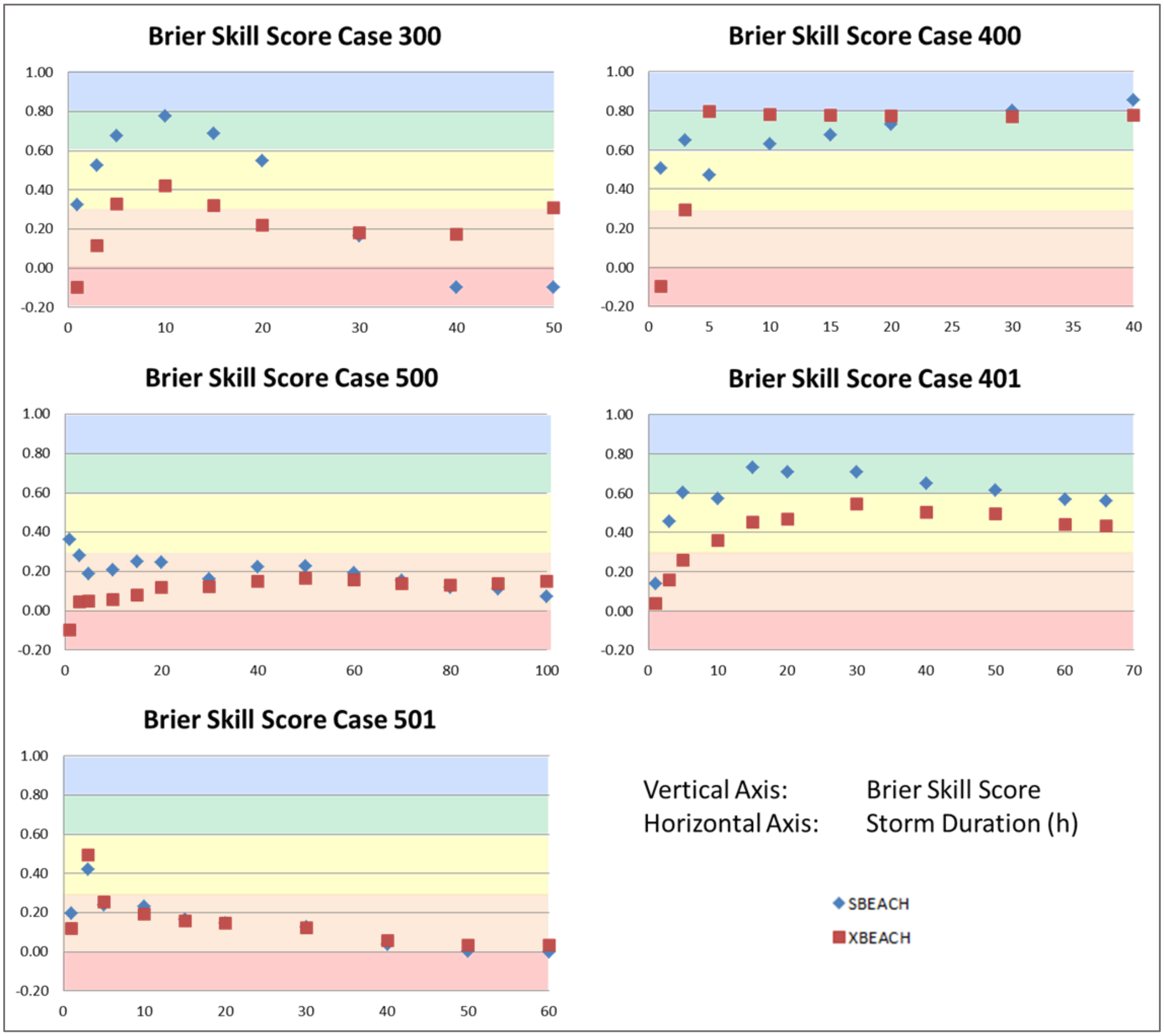


Figure 7-3: SBEACH and XBEACH Brier Skill Scores for Different Storm Durations

From Figure 7-3, it is clear that neither SBEACH nor XBEACH consistently predicted cross-shore beach profile response for different storm durations based on the statistical fits of the modelled beach profiles to the measured beach profiles. SBEACH and XBEACH beach profile predictions for storm durations in Case 400 and Case 401 were quite accurate. Beach profile response for storm durations in Case 300 was moderately accurate for SBEACH and XBEACH. Impact of different storm durations on beach profiles in Case 500 and Case 501 were poorly predicted in SBEACH and XBEACH.

It was generally observed that SBEACH and XBEACH have lower Brier Skill Scores for storms with durations of less than 10 hours, indicating that the models only stabilise after durations of 5 to 10 hours. SBEACH showed greater accuracy than XBEACH for storm durations of less than 30 to 40 hours. For storm durations longer than 40 hours SBEACH and XBEACH BSS values were similar, with XBEACH often achieving slightly greater BSS values than SBEACH. Some of the better profile fits were obtained for storm durations in the region of 10 to 20 hours, which is understandable, since the models were calibrated for storm durations of 5 hours and 15 hours.

SBEACH had more BSS values ranging from good to excellent than XBEACH, indicating that SBEACH is more accurate than XBEACH in predicting cross-shore beach profiles for different storm durations. It is recommended to rather use XBEACH for profile predictions of storms with durations longer than 40 hours. Neither of the models should, however, be used with the assumption that the modelled cross-shore beach profile is accurate.

It is likely that the beach profile response due to longer storms might be more accurate if a longer storm duration case was used than in the calibration case. The shorter storm duration beach profile response will in return be over predicted. The XBEACH results may be more accurate if more parameters are calibrated. Flume data was used to verify the accuracy of the models in predicting beach profile response. It is therefore possible that the effect of wave reflection is much more prominent in the beach profile response to the wave conditions than at a physical site. The reflection of the waves is most likely under predicted, using the numerical models that might lead to less accurate beach profile response predictions.

In practice, beach profiles for calibration are not always available. In these cases, the default calibration parameters should be used, which will lead to less accurate beach profile response predictions than what was observed in this study. Sometimes beach profile surveys exist, but the wave conditions that occurred between two surveys are different from those of the storm that has to be modelled. As seen in the calibration process of Case 300, Case 400 and Case 500 (all cases had the same initial profile and sediment characteristics, but different wave conditions), the calibration parameters differ significantly. Therefore, predictions of storm impact on beach profiles, using a numerical model, calibrated for different wave conditions, will also yield less accurate results than what was observed in this study. Ideally, a numerical model will predict the best beach profile response when the model is calibrated for a storm condition with similar wave conditions and a duration of at least 15 hours.

7.3.2 Assessment of Volumetric Cross-Shore Beach Profile Response

The main parameter studied to evaluate the accuracy of the volumetric beach profile response to different storm durations, was the volume of eroded sediment above the water level. The eroded sediment volumes above the water level were determined for all the different storm durations under all five erosional cases that were analysed. The volumetric beach profile response was determined for all three models (SBEACH, XBEACH and DUNERULE).

For each final beach profile, a percentage relationship was calculated between the actual measured eroded volume above the water level and the eroded volume above the water level predicted by the numerical models. A percentage of 100% indicated that the model correctly estimated the volume of eroded sediment above the water level. Percentages lower or higher than 100% indicated under or over prediction of the eroded volume above the water level respectively. Predictions that were less than 0% or higher than 200% were not included in the graphs. The excluded values were typically obtained for model predictions of storms with durations of one to three hours. Storm durations are typically more than three hours and the excluded results are thus not of importance. A table with the complete volumetric analysis results is provided in Appendix E-5. The plots comparing the volumetric accuracy of SBEACH, XBEACH and DUNERULE for the different modelled cases are shown in Figure 7-4.

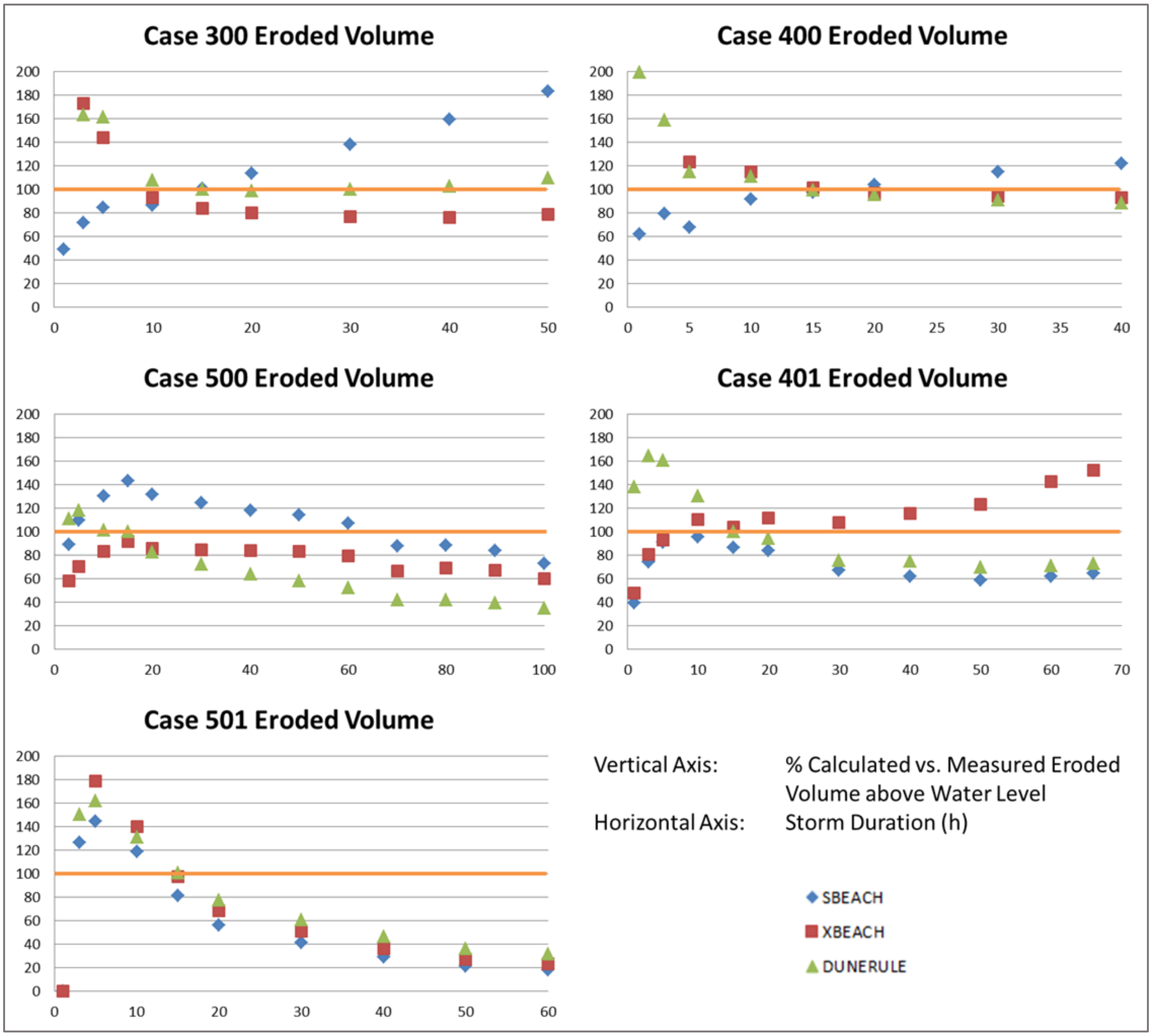


Figure 7-4: Comparison of Volumetric Beach Profile Response for SBEACH, XBEACH and DUNERULE

From Figure 7-4, it was observed that the volumetric responses predicted by the models were slightly more accurate than Brier Skill Scores as discussed in Section 7.3.1. All three numerical models predicted the volumetric response to storms with different durations (of more than 5 hours) in Case 400 very well. The volumetric beach profile response to storm durations studied in Case 501 was poorly predicted, providing marginally accurate results only for storm durations between 10 and 20 hours. The volumetric beach profile response predictions for the different storm durations in the other three cases that were studied, showed significant differences in accuracy between the three numerical models.

None of the studied numerical models should be used to predict volumetric beach profile response for storms with durations of less than 10 hours. It was difficult to identify the numerical model that was the most accurate in predicting beach profile response in terms of the eroded volume above the water level. It was, however, clear that SBEACH is the least reliable model of the three when predicting the volume of eroded sediment above the water level for different storm durations. DUNERULE performed very well for such a simple model. Although DUNERULE provided accurate results for different storm durations in Case 300 and Case 400, XBEACH provided results that are slightly more consistent with relatively good accuracy for all the modelled cases.

From the plotted results, it is advised to use XBEACH or DUNERULE to predict the volumetric beach profile response above the water level. DUNERULE is a much easier model to set up, but the water level calibration is not scientific and there is no default water level value that can be applied when there is a lack of physical data. The calibration approach can only be applied in practice if surveyed beach profile response data is available for the same wave conditions. When time is not a restricting factor in the modelling process it is recommended to use XBEACH, since default calibration parameters are available when there is a lack of physical data for calibration.

Volumetric beach profile response predictions will be more accurate if the calibration profile has a storm duration closer to the storm duration for which beach profile response must be predicted. From the graphs plotted in Figure 7-4 it was noticed that the volumetric beach profile responses for storms of more than 20 to 30 hours were more consistent. It is therefore advised that calibration storm durations of at least 20 hours should be used in order to achieve the most accurate volumetric beach profile response with numerical models for storm durations longer than 20 hours. Using a calibration profile for a longer storm duration will result in less accurate beach profile responses estimated by the models for storms with shorter durations. The accuracy of the XBEACH volumetric profile response predictions can be increased by calibrating more of the XBEACH calibration parameters.

As discussed in Section 7.3.1, calibration beach profiles are not always available in practice. The use of default calibration parameters will lead to less accurate beach profile response predictions than observed in this study. The difference observed between the calibration parameters for cases with the same sediment, initial profile and wave characteristics, indicates that less accurate results will be obtained when the models are calibrated for wave conditions that are not the same as the storm wave conditions that has to be modelled.

The accuracy of the shoreline response predicted by DUNERULE, XBEACH and SBEACH was additionally verified by briefly analysing the predicted shoreline recessions for all the storm durations for the five different cases analysed in this study. The comparison between the measured and calculated beach profiles were done in a similar fashion to the eroded volume comparisons, where a percentage relationship was calculated between the actual measured shoreline recession of the water level elevation contour and the predicted by shoreline recession by the numerical models. In scenarios where no shoreline recession was measured during surveys, but shoreline recession was observed in the model predictions, the percentage accuracy was indicated as 0%. A table with the complete shoreline recession analysis results is provided in Appendix E-5. The plots comparing the shoreline recession accuracy of SBEACH, XBEACH and DUNERULE for the different modelled cases are shown in Figure 7-5.

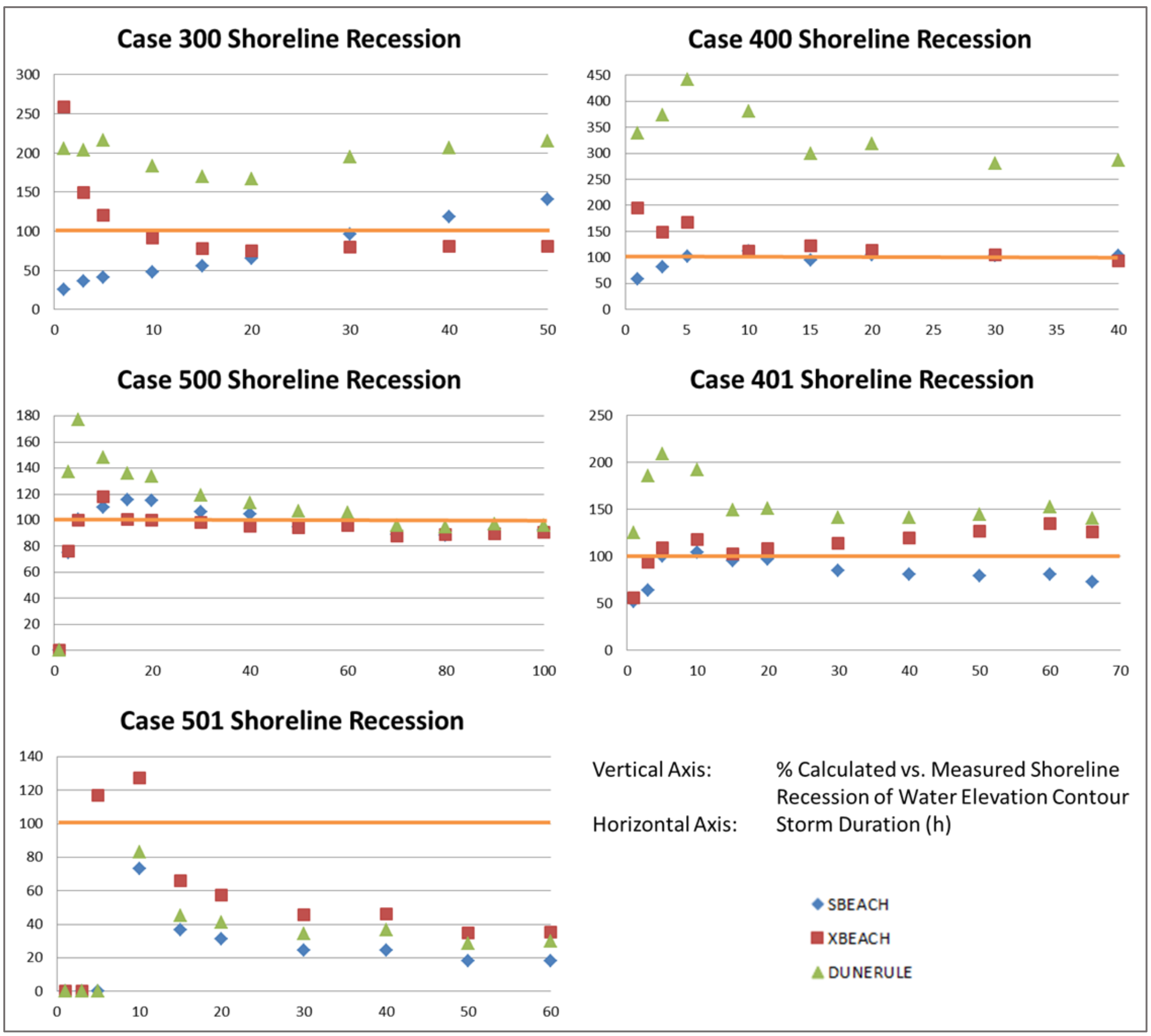


Figure 7-5: Comparison of Shoreline Recession Accuracy for SBEACH, XBEACH and DUNERULE

Case 501 was once again ill predicted by all three numerical models and was thus not included in the process of identifying the most appropriate numerical model to predict shoreline recession. For storm durations of less than 5 to 10 hours, the predictions were more inaccurate than for longer storm durations, which agrees with the observations made in the statistical and volumetric response analysis. DUNERULE over-estimated the shoreline recession by a large margin for three of the five cases and only predicted accurate shoreline recession for Case 500. SBEACH and XBEACH, however, also predicted accurate shoreline recession for Case 500. From the graphs, it was observed that both SBEACH and XBEACH predicted the shoreline recession relatively accurately for Case 400 and Case 500. The shoreline recession was better predicted by XBEACH for Case 300, but SBEACH estimated the shoreline recession of Case 401 more accurately. From the five analysed cases, it appeared that XBEACH reached consistent shoreline recession accuracies for different storm durations faster and more often than SBEACH. The XBEACH model accuracy can also be improved more than the SBEACH accuracy, since more calibration parameters can be adjusted. It is therefore recommended to use XBEACH for the prediction of shoreline recession.

7.3.3 Visual Analysis

The final profiles modelled by SBEACH and XBEACH were plotted along with the final profiles measured in the CERC Large Wave Tank. Figure 7-6 shows the plotted profiles for a storm with a duration of 30 hours in Case 300. The plots of all the profiles for different storm durations for each CERC Large Wave Tank case are provided in Appendix E-6. Table 7-5 summarises the observations made for the different storm durations observed in each CERC Large Wave Tank case.

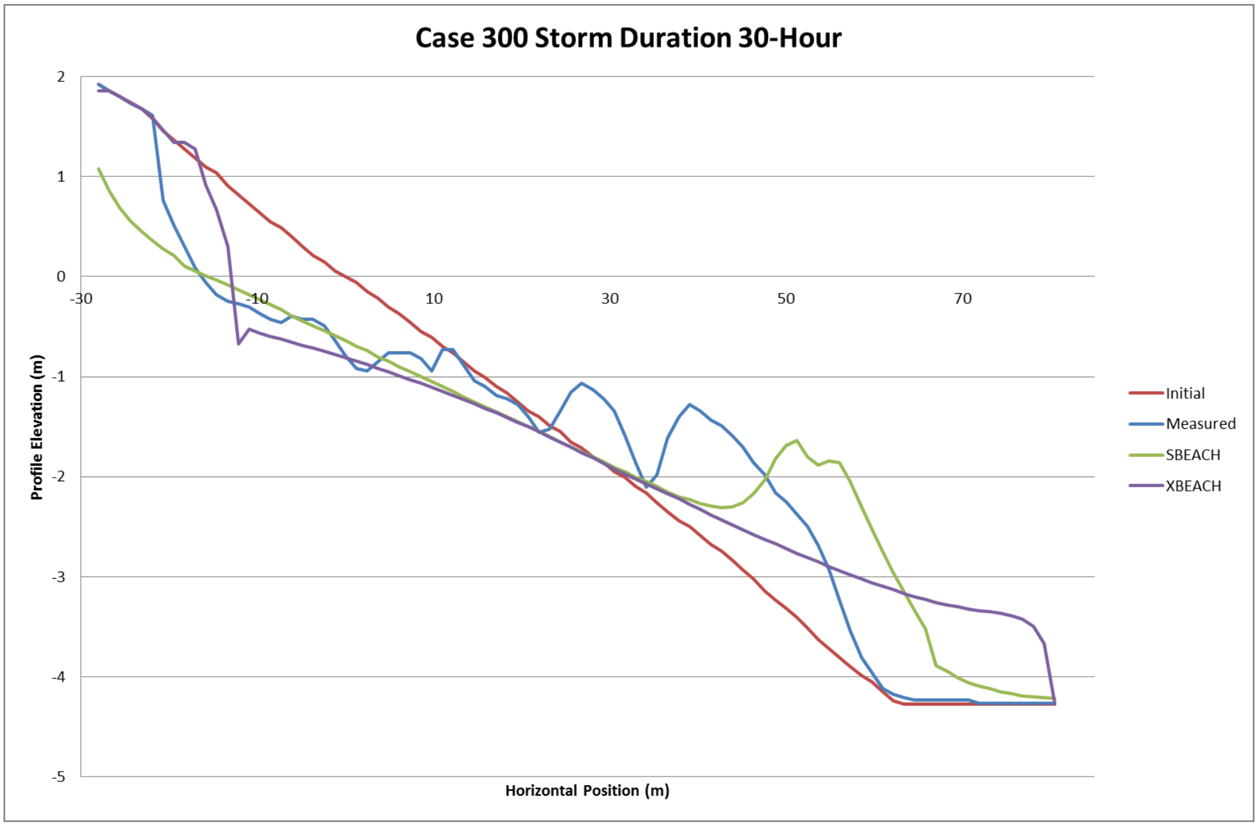


Figure 7-6: Measured, SBEACH and XBEACH Plots of Beach Profile for a 30-Hour Storm in Case 300

Table 7-5: Visual Analysis of Profile for Different Storm Durations

Case	Visual Analysis of Profile for Different Storm Durations
300	SBEACH quite accurately predicted the seaward position of the main offshore bar for storms with durations less than 20 hours. The volume of the offshore bar was, however, under-predicted. For storm durations of 20 hours or longer the offshore bar migrated too far offshore compared to the surveyed data, but the volume of the bars seemed more accurate. The profile of the beach above the water level was not predicted accurately in SBEACH at all. No secondary bars were predicted either. XBEACH on the other hand showed much more accurate predictions of the landward end of the beach profile than SBEACH. No offshore bars were, however, predicted in XBEACH resulting in very poor correlation between the surveyed and XBEACH profiles beyond 30m offshore.

400	SBEACH predicted the offshore bar slightly too landward for the shorter storm durations, but as the storm durations increased, the bar position and bar volume were more accurately predicted. Both SBEACH and XBEACH predicted the landward end of the beach profile extremely accurately for storm durations longer than 5 hours. XBEACH predicted an offshore bar for the shorter storm durations that was positioned too far seaward. For longer storm durations, the offshore bar was smoothed out in the XBEACH predictions and was not representative of the measured profile prediction.
500	In Case 500, SBEACH predicted offshore bars that were positioned more landward than the measured offshore bars for all the storm durations. The volume of the predicted offshore bars was also smaller than the measured bars. The beach profiles above the water levels were well predicted by SBEACH and XBEACH. For storm durations of longer than 70 hours, the profile predictions above the water levels became less accurate in SBEACH and XBEACH. For the beach profile from the water elevation position to 15m offshore, XBEACH produced acceptable, but slightly less accurate profile predictions than SBEACH. No prominent offshore bars were modelled in XBEACH.
401	SBEACH predicted the beach profile responses for all the storm durations longer than 3 hours very well. The landward end of the profiles and the main offshore bars are accurately estimated. Due to the fact that SBEACH only models the primary offshore bar, the secondary bars formed during the experimental runs were not modelled, leading to inaccurate predictions of the beach profiles between 5m and 25m offshore. XBEACH did not produce accurate final beach profiles for any of the storm durations. The landward ends of the profiles were relatively well predicted, but the erosion areas were over-predicted. Since no offshore bars were formed with the XBEACH model, the seaward end of the XBEACH profiles had no similarity to the measured profiles.
501	In Case 501 neither SBEACH nor XBEACH produced final profiles for any storm durations that were representative of the actual measured profiles.

From the visual analysis it was deduced that SBEACH provided more representative final profiles for the different storm durations. SBEACH does not predict secondary offshore sand bars at all, which explains why the Brier Skill Scores (statistical fits) did not reflect the same level of accuracy that was observed visually.

Although XBEACH provided rather accurate profiles for the landward section of the analysed profiles, the seaward sections lacked prominent offshore features such as sand bars. The poor final profile predictions by XBEACH may be attributed to the XBEACH set-up that mainly focusses on the effect of long waves on cross-shore sediment transport. Due to the fact that the analysed experimental runs were done with monochromatic short waves, no long waves were forced, which might have led to inaccurate profile response predictions.

The beach profile responses to all the storm durations in Case 501 have been predicted poorly in the statistical, volumetric and visual analysis. After the visual analysis was done, a possible reason for the poor predictions was found. Since the initial measured profiles had little to no sediment movement above the water level for shorter storm durations, the calibration process was much more sensitive to any modelled sediment movement above the water level. For example, the 5-hour storm duration case had a measured volume of sediment eroded above the water level of $0.4m^3/m$. A model prediction of $0.2m^3/m$ or $0.6m^3/m$ during calibrations runs led to extremely inaccurate volumetric responses based on percentage differences, even though the quantitative difference of $0.2m^3/m$ is not of significance on the scale of the overall set-up. Since the models were calibrated using the percentage accuracy of profiles where very little sediment erosion above the water levels occurred, the profiles were essentially calibrated to induce as little sediment transport as possible. The calibration did not, however, represent the sediment transport over the entire profile and therefore led to inaccurate model predictions in SBEACH, XBEACH and DUNERULE. In the future, the calibrations should be done for storm durations of at least 20 hours in order to provide more accurate beach profile response predictions.

7.4 Accuracy of Model Response Prediction of Beach Profile due to Long Waves

7.4.1 Assessment of Final Cross-Shore Beach Profile Prediction

As already discussed in Section 5.5.3.1, the calibration of the numerical models (XBEACH and SBEACH) for the SUSCO large wave tank experiments on long waves, was not successful. It was decided to analyse the accuracy of the numerical models, in predicting cross-shore beach profile response to long waves, by using the default values of the calibration parameters. From the calibration process, it was assumed that the Brier Skill Scores for all the model runs would be very low, indicating bad final profile predictions. Even so, the Brier Skill Scores were calculated for all the models and are provided in Appendix F-5.

As expected, no remarkable conclusions were drawn from the Brier Skill Score results. The Brier Skill Scores for the SBEACH model runs on free long waves, all yielded negative results. Only one positive Brier Skill Score (0.06) was obtained in XBEACH for one of the bichromatic runs (Run B_A2).

The Brier Skill Scores reflected that the final profile predictions by both SBEACH and XBEACH were not representative of the measured cross-shore beach profile responses under combined monochromatic and free long wave conditions. XBEACH also did not provide representative results of the measured cross-shore beach profile responses under bichromatic wave conditions.

The Brier Skill Scores may be improved through calibration of the models. But, for the large wave tank experiments used in this study, calibration of the models only resulted in final cross-shore beach profiles where little to no cross-shore sediment transport was observed. The small wave conditions might be part of the reasons why the cross-shore numerical models failed to predict accurate cross-shore beach profile response. As discussed in Section 5.5.3.1, both SBEACH and XBEACH were developed especially for predictions of beach profile response under storm wave conditions. The experimental conditions did not specifically represent storm wave conditions and the poor Brier Skill Scores exposed the shortcomings of both models to predict beach profile response under less severe wave conditions.

7.4.2 Assessment of Volumetric Cross-Shore Beach Profile Response

The percentage differences between the measured large wave tank eroded volumes above the still water level and the numerically modelled results were determined and are provided in Appendix F-5. Like the Brier Skill Score results, the eroded volumes above the water levels were poorly predicted by both SBEACH and XBEACH under combined monochromatic and free long wave conditions. The best volumetric result was obtained by SBEACH, but was still 99% smaller than the actual measured eroded volume above the water level.

The XBEACH bichromatic beach profile responses did not deliver accurate predictions either. The XBEACH modelled Run B_E2 had an eroded volume above the water level that was 87% of the measured eroded volume. Although this percentage indicated relative accuracy, the same amount of accuracy was not displayed in any of the other XBEACH model runs.

Calibration might have improved the results, but as already mentioned, the best results were obtained when the models were calibrated in such a way that no sediment transport occurred between the initial and final profiles. Since the quantitative accuracy of the volumetric predictions were inaccurate, it was decided to compare the measured and modelled volumetric responses between the monochromatic cases and the long wave cases.

In other words, the measured sediment volumes eroded above the still water level in the case where only monochromatic waves were used, were compared to the measured volumes eroded above the still water level where combined short and long waves were used. The same comparison was done for the modelled eroded volumes above the still water level for SBEACH and XBEACH respectively. Table 7-6 summarises the comparisons in terms of percentage volumes eroded above the still water level. A positive percentage indicates that the eroded volume increased or that the accreted volume decreased.

Table 7-6: Comparison of Eroded Sediment Volume Responses under Monochromatic and Combined Monochromatic and Free Long Waves

Comparison	Measured	SBEACH	XBEACH
MA vs. C_A2	-25%	-322%	+30%
MA vs. C_A4	-94%	+26479%	-30%
ME vs. C_E4	-97%	+31%	+105%

From Table 7-6 it is clear that neither the SBEACH nor XBEACH predictions represented the cross-shore beach profile responses to free long waves (based on the monochromatic beach profile responses) accurately. None of the modelled eroded sediment volume differences between the monochromatic and combined wave conditions agreed with those recorded during the physical experiments. It is clear that the SBEACH and XBEACH model set-ups to represent free long waves as varying water levels was not successful with regards to the modelled eroded sediment volumes above the water levels.

Another factor that might also have played a role in the poor model predictions, is that SBEACH and XBEACH do not model cross-shore beach profile predictions under smaller wave conditions very well. Very little sediment displacement occurred in the physical experiments and therefore, a big percentage difference between the measured and eroded volumes might not necessarily indicate a big quantitative difference. For example, in Run C_E4, the percentage difference between the eroded sediment volumes that was measured and modelled by SBEACH was 8018%. The quantitative difference was 0.424m^3/m, which is very small compared to erosion that might occur during storms.

The XBEACH cross-shore beach profile predictions under bichromatic wave conditions were also analysed based on the differences between the monochromatic and bichromatic beach profile responses. Table 7-7 shows the results that were obtained through this analysis method.

Table 7-7: Comparison of Eroded Sediment Volume Responses under Monochromatic and Bichromatic Waves

Comparison	Measured	XBEACH
MA vs. B_A1	+73%	+17%
MA vs. B_A2	+111%	-65%
ME vs. B_E1	-128%	-23%
ME vs. B_E2	-26%	-64%

Three out of the four model runs predicted an eroded volume difference that agreed with the measured runs in terms of whether more or less erosion or accretion occurred in the bichromatic wave cases than in the monochromatic wave cases. For example, the surveyed results indicated that the amount of offshore sediment transport increased (or the amount of onshore sediment transport decreased) from the monochromatic to Run B_A1 bichromatic waves conditions. The same observation was made in XBEACH, although a smaller difference occurred in the model run than in the measured run. Based on the results, XBEACH does not predict cross-shore sediment transport under bichromatic wave conditions accurately. With proper model calibration and different physical data sets, conclusions that are more concrete might be drawn.

The assessment of the accuracy of the models in predicting shoreline recession yielded more or less the same conclusions as the accuracy assessment of the eroded volume of sediment above the water level. The percentage differences between the measured and modelled shoreline recessions under combined monochromatic and free long wave conditions and bichromatic wave conditions, are tabulated in Appendix F-5.

Neither SBEACH nor XBEACH predicted shoreline recession that represented the actual measured shoreline responses to free long waves added to monochromatic wave conditions. For the bichromatic wave cases modelled in XBEACH, only one model run (Run B_E2) predicted shoreline recession that was representative of the measured shoreline recession. The results were, therefore, analysed in a similar manner as the eroded sediment volumes above the water level. Table 7-8 summarises the comparisons between the monochromatic and combined monochromatic and free long wave shoreline recessions for the measured and modelled results. A positive percentage indicates that the shoreline receded more than in the monochromatic case, or shifted a shorter distance seaward as in the monochromatic case.

Table 7-8: Comparison of Shoreline Recession Responses under Monochromatic and Combined Monochromatic and Free Long Waves

Comparison	Measured	SBEACH	XBEACH
MA vs. C_A2	+581%	0%	+4%
MA vs. C_A4	-312%	0% (+0.8m)	+19%
ME vs. C_E4	-2174%	+33%	+44%

The numerical models did not accurately represent the trends of the responses of the beach profiles under monochromatic and combined monochromatic and free long wave conditions. In the measured cases where the shorelines shifted seawards under combined wave conditions, the models predicted a landward recession of the shoreline. In the one scenario where the shoreline receded in the measured results, the models predicted much smaller shoreline recession distances. It is clear that the proposed method to model free long waves as varying water levels, were not successful when considering the poor shoreline recession results. The fact that the monochromatic beach profile responses were also poorly predicted indicates that other factors might also have influenced the inaccurate beach profile responses. Two of the main possible factors are the small wave conditions and small amount of sediment displacement that occurred above the still water level as discussed earlier in this section.

The comparisons between the monochromatic and bichromatic wave impact on the shoreline recession are provided in Table 7-9.

Table 7-9: Comparison of Shoreline Recession under Monochromatic and Bichromatic Waves

Comparison	Measured	XBEACH
MA vs. B_A1	+300%	-11%
MA vs. B_A2	+981%	-53%
ME vs. B_E1	+363%	-15%
ME vs. B_E2	+2903%	-41%

From the shoreline recession comparisons, it is clear that the bichromatic wave conditions caused shoreline recessions that were larger than the shoreline recessions under the monochromatic wave conditions. This measured response was not reflected in the model responses, where less shoreline recession was observed under bichromatic wave conditions than under monochromatic wave conditions. Although the plans are in the pipeline, it is not yet possible to enter the separate bichromatic wave conditions in XBEACH. At this moment, an estimate of the representative period and bound long wave length is required as input. The cause of the inaccurate cross-shore beach profile predictions might be because XBEACH currently models simplified bichromatic wave conditions instead of the actual superimposed bichromatic waves.

7.4.3 Visual Analysis

In Figure 7-7 the beach profile responses for Run C_A4 (accretive monochromatic conditions) that were measured in the tank and modelled with SBEACH and XBEACH are provided. The measured and modelled results of the erosive monochromatic and free long wave conditions (Run C_E4) are plotted in Figure 7-8. The rest of the plots are available in Appendix F-6.

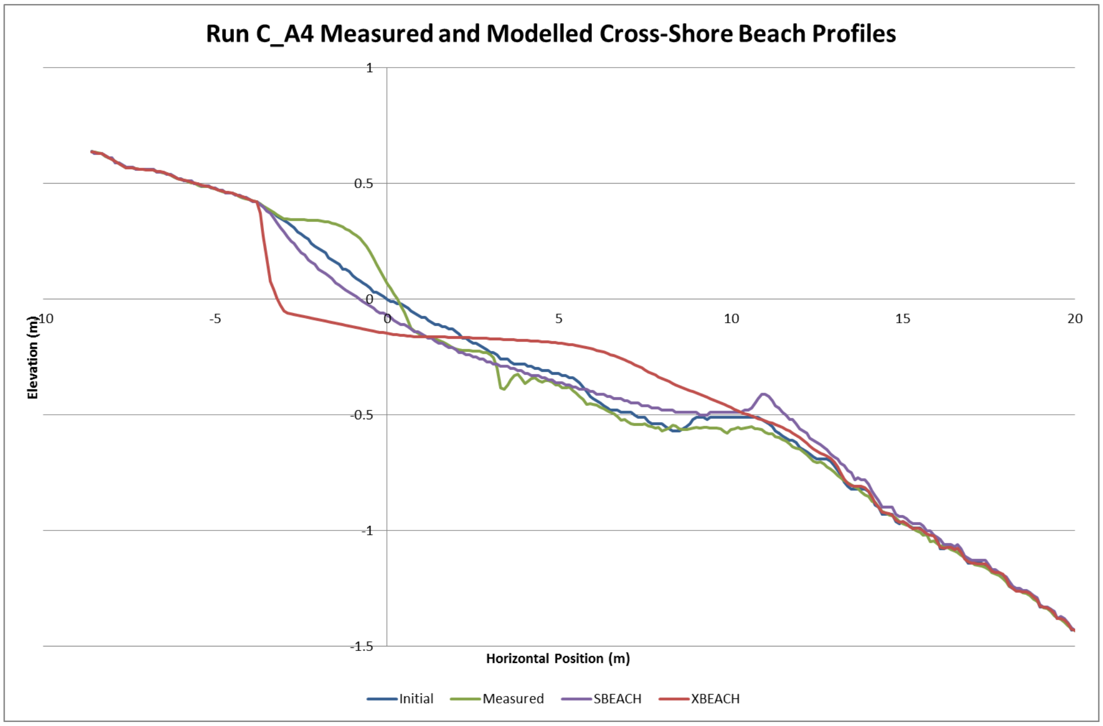


Figure 7-7: Measured and Modelled Cross-Shore Beach Profile Responses under Accretive Monochromatic and Free Long Waves

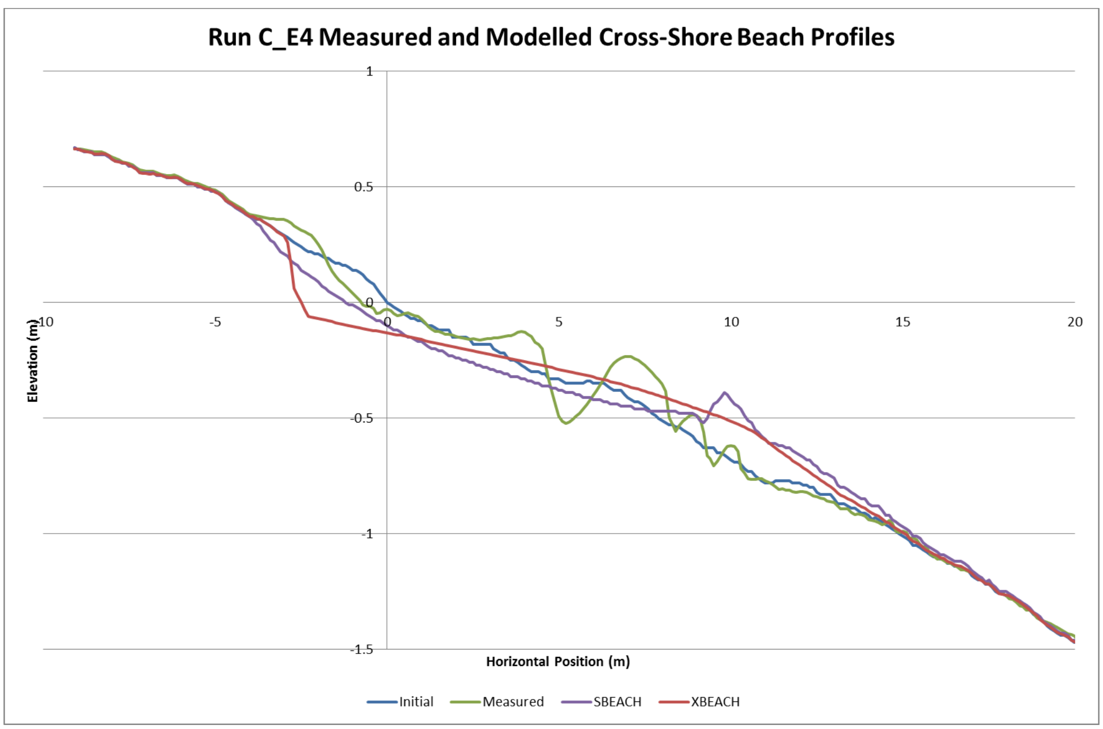


Figure 7-8: Measured and Modelled Cross-Shore Beach Profile Responses under Erosive Monochromatic and Free Long Waves

Under the accretive wave conditions, it was observed that the slight offshore sand bar that was present in the initial profile, was smoothed out after 138 minutes of combined short and long wave impact. The sediment was transported from the slight offshore sand bar to the shoreline, where it was deposited predominantly above the still water level. The SBEACH results predicted a growth in the offshore sand bar as the sediment eroded above the still water level. SBEACH did, however, exhibit a relatively accurate cross-shore beach profile response from the shoreline to the position of the offshore bar. XBEACH on the other hand predicted the beach profile response above the shoreline less accurately than SBEACH, although the response seaward of the offshore sand bar peak was more accurate than SBEACH. Between the landward point of no significant sediment transport and the peak of the offshore sand bar, the XBEACH results were not representative of the measured beach profile response at all.

From the measured results for the erosive wave conditions, it was noticed that a dominant offshore bar was formed with a trough landward of the bar. A secondary sand bar developed landward of the trough. Although erosion occurred directly above the still water level, some accretion occurred higher up on the beach face. Although SBEACH also predicted a dominant offshore sand bar, the location of the sand bar was predicted too far offshore. Since the SBEACH model does not include secondary sand bars in its profile predictions, none of the measured secondary bars were present in the SBEACH model response to erosive monochromatic and free long wave conditions. The eroded sediment volumes shoreward of the sand bar was over predicted in SBEACH and the accretion that occurred at the top of the beach face was not accounted for. The XBEACH model runs over predicted the amount of erosion that occurred above the sea level even more than the SBEACH model did. No prominent offshore sand bar was formed in the XBEACH model.

Figure 7-9 provides the measured and modelled beach profile responses for Run B_A1, which represented the typical beach profile responses to bichromatic wave conditions. The rest of the bichromatic final beach profiles are provided in Appendix F-7.

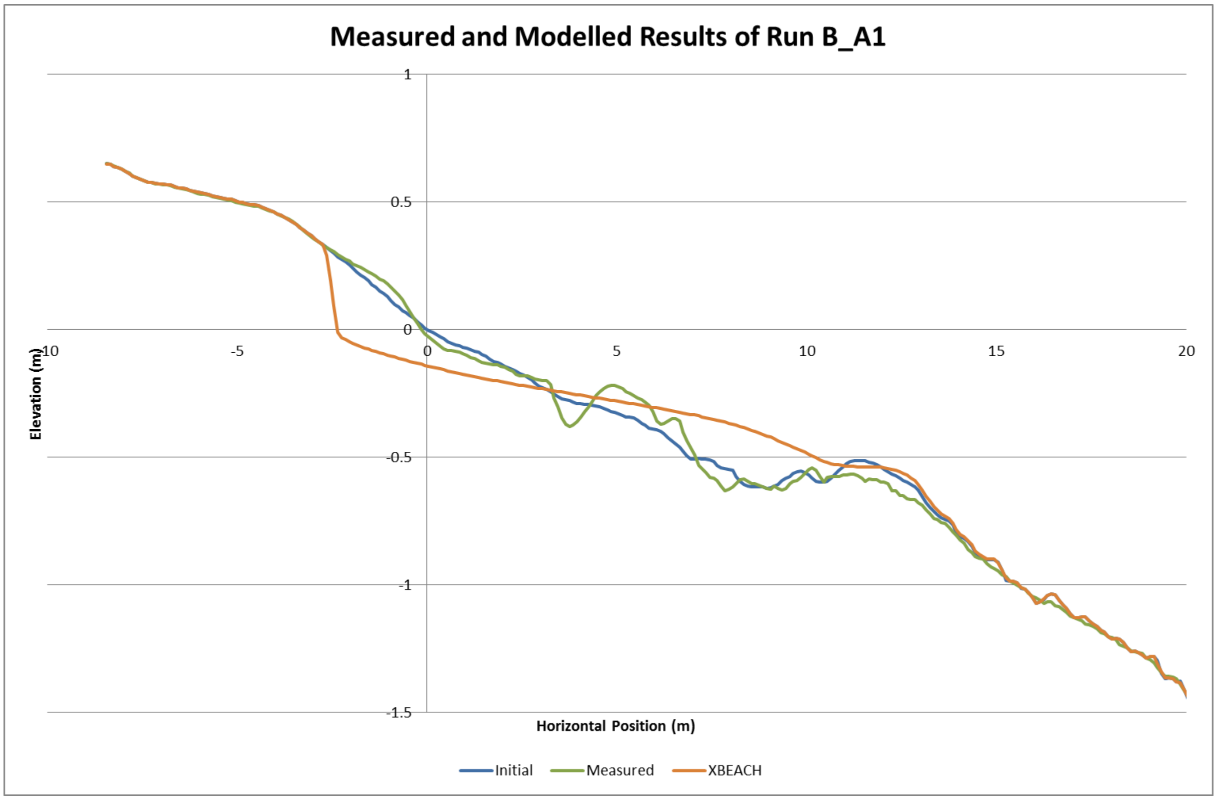


Figure 7-9: Measured and Modelled Cross-Shore Beach Profile Responses under Accretive Bichromatic Wave Conditions

As observed from the measured beach profile response to bichromatic wave conditions, the slight offshore sand bar that was present in the initial profile, was smoothed out. The sediment was transported from the sand bar in a landward direction where it deposited to form a prominent offshore bar. Slight erosion of the beach profile occurred just below the water level. The profile above the water level accreted. The measured response was not reflected in the XBEACH results. XBEACH predicted a large volume of sediment erosion above the still water level, which resulted in inaccurate sediment accretion seaward of the shoreline.

From the visual analysis it was concluded that SBEACH provides more accurately beach profile response predictions to free long wave conditions than XBEACH. The SBEACH results, however, did not predict the beach profile responses accurately enough to deem the SBEACH responses representative of the actual beach profile responses to free long waves. Possible reasons for the poor accuracies presented in the SBEACH and XBEACH model results are the model set up to represent free long waves as varying water level and the relatively calm wave conditions that were used for the experiments.

The XBEACH model results clearly showed a lack of accurate predictions of cross-shore beach profile responses under bichromatic wave conditions. The bichromatic wave option of the XBEACH model is not completely representative of the actual bichromatic wave conditions, since only one regular wave condition can be specified along with an indicative long wave period. The superimposed waves caused by the bichromatic waves, therefore, are estimated in XBEACH instead of calculated. The poor results that were obtained in this study indicate that more attention should be given to the XBEACH model formulation regarding bichromatic wave regimes.

7.5 SUMMARY

Chapter 7 entailed the assessment of the selected numerical models in predicting accurate cross-shore beach profile responses under varying water levels, different storm durations and long waves respectively. The assessments were done by modelling prototype wave flume data using the respective models and comparing the modelled results with the physical results.

Case 911 from the CERC Large Wave Tank experiments (Kraus & Larson, 1988) was used to assess the accuracies of the numerical models in predicting beach profile responses under varying water levels. Twenty-three independent cases of water level variation was extracted from Case 911 and were modelled in SBEACH and XBEACH. The accuracy of DUNERULE could not be assessed, since varying water levels could not be modelled in DUNERULE.

The results indicated that the SBEACH models predicted cross-shore beach profiles that were much more representative of the measured beach profile shapes than the XBEACH modelled profiles. Quantitatively, neither of the models consistently predicted representative cross-shore beach profile responses. XBEACH predicted eroded volumes above the water levels that were more accurate than the SBEACH results. SBEACH typically over predicted the eroded volumes above the water levels. Based on the shoreline recession results, SBEACH provided results that were marginally more accurate than the XBEACH results. In general, the SBEACH results were more consistent with the exception of the eroded volumes above the water levels. Both models showed poor cross-shore beach profile predictions under accretive conditions.

In order to assess the accuracies of the models in predicting cross-shore beach profile evolution under different storm durations, five erosive experimental cases were selected from the CERC Large Wave Tank experiments (Kraus & Larson, 1988). Each case had several intermediate beach profiles recordings that were used as different storm durations in the model set-ups. The accuracies of SBEACH, XBEACH and DUNERULE were analysed.

From the analysis, all three models showed relatively accurate predictions for the eroded volumes above the water levels and shoreline recession. The proposed method to calibrate DUNERULE by adjusting the water level elevation proved to be successful. The DUNERULE shoreline recession results, however, were often over predicted especially in comparison with the SBEACH and XBEACH results. The SBEACH and XBEACH results both showed reliable accuracy when predicting the volume of eroded sediment above the water level and the shoreline recession. The XBEACH model, however, did not predict the actual beach profile shape as well as SBEACH. Based on the studied parameters, it is thus recommended to use SBEACH for the predictions of beach profile response under different storm durations.

The accuracies of the models to predict cross-shore beach profile response under long wave conditions were assessed based on SUSCO Large Wave Tank experiments (Vicinanza, 2010). Only free long waves and bound long waves formed under bichromatic wave conditions were studied. There was no possibility to specify long waves in DUNERULE and therefore DUNERULE was excluded from this part of the study. Free long waves could not be entered as part of the model input parameters in SBEACH and XBEACH. It was decided to represent the free long waves as small, but frequent, water level variations. Only XBEACH has the capacity to model bichromatic wave conditions.

The results indicated that the method to estimate free long waves as water level variation was not successful. Neither SBEACH nor XBEACH modelled scenarios where accretion occurred above the water level accurately. SBEACH did however provide beach profile responses that were visually more representative of the measured beach profile responses than XBEACH. The XBEACH model predictions under bichromatic wave conditions failed to deliver accurate results.

In general it is possible to obtain XBEACH results that are more accurate, since only four parameters were calibrated and an extensive list of parameters can still be calibrated. In practice it is often the case that data is not available to calibrate the models with, in which case the SBEACH and XBEACH model prediction accuracies will decrease. It was clear that none of the models could accurately predict scenarios of accretion. When very little sediment displacement occurred in the physical data, the models also struggled to predict representative cross-shore beach profiles. Unfortunately, the accuracy of DUNERULE was only assessed for the storm duration predictions. In that part of the study, it was clear that DUNERULE predicted relatively accurate beach profile responses, considering how simple the model is.

8 CONCLUSION

8.1 DISCUSSION

Firstly, a literature study was conducted on all the literature that was applicable to the scope of this thesis. The knowledge that was gained from the literature study was applied to develop and conduct a numerical model study. The goal of the numerical model study was to assess the sensitivity and accuracy of three selected numerical models in predicting short term cross-shore beach profile responses to varying water levels, different storm durations and bound and free long waves. Based on the assessments, the most appropriate cross-shore numerical models to model varying wave conditions, different storm durations and long waves were respectively identified.

Literature on the effect of varying water levels, storm duration and long waves was available and gave insight into how the numerical models were expected to behave. The most recent literature suggested that a short-term rise in water level causes a landward shift of the offshore sandbar and *vice versa* (Jensen *et al.*, 2009). The reason for this behaviour is that a change in water level results in a shift of the wave breaking point. There is a relationship between cross-shore beach profile erosion and storm durations, but this relationship is not linear. As storm durations increase, more cross-shore sediment erosion takes place. The rate of increase in the cross-shore sediment erosion, however, decreases with time, since the beach profile develops to reach an equilibrium profile under the specific wave energy conditions (Dalrymple, 1976). Increased sediment transport is expected under free and bound long wave conditions (Cáceres & Alsina, 2016) due to an increase in the wave breaking area. Baldock *et al.* (2010) found that free long waves promote onshore sediment transport and bound long waves promote offshore sediment transport.

In this study, an attempt was made to assess whether the selected cross-shore numerical models could accurately predict cross-shore beach profile response to varying water levels, storm durations and long waves. Firstly, SBEACH, XBEACH and DUNERULE were selected as the three cross-shore sediment transport and morphology numerical models. The sensitivity of each of the models to varying water levels, storm durations and long waves was analysed in order to identify any models that were not able to predict cross-shore beach profile evolution under the impact of the studied parameters.

After the sensitivity analysis was done, physical data were obtained to which the numerical model responses could be compared to, in order to assess the model accuracies. An attempt was made to calibrate the models, after which the physical scenarios were modelled with the selected numerical models. The beach profile responses of the physically measured and numerically modelled cases were compared based on final profile predictions, eroded volumes above the water levels, shoreline recession and visual observations. Based on the comparisons, conclusions were drawn on whether the numerical models could accurately predict cross-shore beach profile responses. Recommendations were also made on which numerical models should be used for cross-shore beach profile predictions under varying water levels, different storm durations and long waves respectively.

8.2 Key Findings

SBEACH, XBEACH and DUNERULE were selected for analysis in this study. A sensitivity study was done by modelling synthetic conditions in the different numerical models. From the sensitivity study, conclusions were drawn on the ability of the models to predict cross-shore beach profile response to varying water levels, different storm durations and long waves. The main conclusions that were drawn were:

- that all three models showed sensitivity to different water level inputs, but that DUNERULE showed volumetric sensitivity that does not agree with findings from previous studies;
- that all the models showed a similar trend in sensitivity towards different storm durations;
- that DUNERULE completely lacked the option to determine the effect of long waves on beach profile responses;
- that free long waves had to be modelled as varying water levels in SBEACH and XBEACH, since free long waves could not specifically be modelled in either of the models;
- that SBEACH and XBEACH showed sensitivity to free long waves modelled as varying water levels;
- that only XBEACH had the ability to model bichromatic wave conditions and showed sensitivity to bichromatic wave input compared to monochromatic wave input, and
- that apart from DUNERULE that was developed only for erosional conditions, neither SBEACH nor XBEACH modelled any scenarios where accretion occurred, even though calm wave conditions were also modelled.

Data from physical experiments were collected and modelled in the different numerical models. The measured and modelled results were compared in order to draw conclusions on the accuracy of the models to predict cross-shore beach profile response to the different input parameters studied in this thesis.

It was found that DUNERULE could not predict beach profile responses when the water level is varied throughout the duration of impact. SBEACH and XBEACH were both inconsistent in predicting accurate beach profile responses to varying water level conditions. It was concluded that SBEACH predicted the most accurate cross-shore beach profile responses under varying water level conditions, but that the predictions were still not representative of the actual beach profile responses.

All three models provided relatively consistent predictions of cross-shore beach profile responses to different storm durations. DUNERULE proved that even though it is a very simple model, it could still predict representative erosion volumes and setback lines. XBEACH provided results that were quantitatively more accurate than the SBEACH results, but SBEACH predicted final beach profile shapes that were more representative of the actual beach profile evolutions. For quantitative predictions, it is thus recommended to use XBEACH, but to understand the response of the beach profile in terms of offshore formations, SBEACH should be used.

The proposed method to model free long waves as small and frequent water level variations in SBEACH and XBEACH proved to be unsuccessful. Neither of the models predicted acceptable quantitative or qualitative beach profile responses. The impact of bichromatic waves on cross-shore beach profile responses was poorly predicted by XBEACH. A possible explanation for this is the fact that XBEACH requires estimated bichromatic wave input, specified as a representative short wave and free long wave, instead of two monochromatic wave conditions that are superimposed.

In general, it was observed that none of the models (with the exception of one SBEACH model run) predicted accretion when accretion occurred in the physical scenarios. DUNERULE specifically models only erosion. In SBEACH, the empirical sediment transport predictor has been under scrutiny before (Thieler *et al.*, 1999) and is the main reason why SBEACH failed to predict accretive conditions. The XBEACH numerical model was developed under the assumption that long waves have a more significant role in sediment transport than short waves. Although XBEACH was able to model beach profile responses under monochromatic conditions, it was clear from the results that XBEACH lacked the ability to predict cross-shore beach profile evolutions under regular wave conditions accurately.

In physical scenarios, where little, but significant, sediment transport occurred above the sea level, the numerical models struggled to provide accurate results. These sediment transport conditions typically occurred under calm wave conditions. A possible reason for the poor model predictions is that the models were all developed to model the effect of storm conditions and not specifically calm conditions.

8.3 Recommendations for Further Studies

Only four parameters were calibrated for the XBEACH model cases. These parameters were selected based on recommendations from previous studies, but it could be that the calibration of some other parameters may lead to more accurate cross-shore beach profile predictions. It is recommended to explore the other calibration parameters of XBEACH specifically with the aim to gain more accurate final beach profile shapes.

The focus of further studies should be to obtain more relevant physical data, specific to water level variation and long waves. It would be of value if field data could be used to assess the accuracy of the models in predicting beach profile responses to different storm conditions and varying water levels. The Coastal Engineering Research Center (CERC) Field Research Facility has data that can be used to specifically evaluate tidal effects and storm duration on cross-shore beach profile responses. This data was unfortunately not available for this study, but should be included in future studies. It is not feasible to isolate the effect of long waves on cross-shore beach profile development from field data and it is therefore recommended to do more experimental runs with long waves in prototype wave flumes.

XBEACH has a non-hydrostatic mode that enables short waves to be resolved individually. In this study, only the hydrostatic mode was investigated and it is, therefore, recommended to also investigate the non-hydrostatic mode in future studies.

9 REFERENCES

Allen, T. 1968. *Particle size measurement.* London: Chapman & Hall.

Argonne National Library. 2016*. Total porosity* [Online]. Available: http://web.ead.anl.gov/resrad/datacoll/porosity.htm [2016, August 1].

Baldock, T.E., Alsina, J.A., Cáceres, I., Vicinanza, D., Contestabile, P., Power, H. & Sanchez-Arcilla, A. 2011. Large-scale experiments on beach profile evolution and surf and swash zone sediment transport induced by long waves, wave groups and random waves. *Coastal Engineering,* 58:214-227.

Baldock, T.E., Holmes, P., Bunker, S. & van Weert, P. 1998. Cross-shore hydrodynamics within an unsaturated surf zone. *Coastal Engineering*, 34:173-196.

Baldock, T.E., Manoonvoravong, P. & Pham, K.S. 2010. Sediment transport and beach morphodynamics induced by free long waves, bound long waves and wave groups. *Coastal Engineering*, 57(10):898-916.

Bernadara, P. 2012. On the two step threshold selection for over-threshold modelling. *Coastal Engineering Proceedings*, 1(33):1-6.

Bruun, P. 1954. Coast erosion and the development of beach profiles. Technical Memorandum No. 44, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bruun, P. 1962. Sea-level rise as a cause of shore erosion. *Journal of the Waterways and Harbours Division*, 88(1-3):117-130.

Cáceres, I. & Alsina, J.M. 2016. Suspended sediment transport and beach dynamics induced by monochromatic conditions, long waves and wave groups. *Coastal Engineering*, 108:36-55.

Caldwell, J.M. 1959. Shore erosion by storm waves. Miscellaneous Paper No.1-59, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CEM (Coastal engineering manual). 2002. U.S. Army Corps of Engineers. Coastal Engineering Manual: 1110-2-1100. Washington, DC.

CEM (Coastal engineering manual): Appendix A: Glossary of coastal terminology. 2003*.* U.S. Army Corps of Engineers. Coastal Engineering Manual: 1110-2-1100. Washington, DC..

Chadwick, A., Morfett, J. & Borthwick, M. 2004. *Hydraulics in civil and environmental engineering*. London: Spon Press.

Chang. H., Chen, W. & Liou, J. 2015. Shifting the waterlines of satellite images to the mean water shorelines considering wave runup, setup, and tidal variation. *Journal of Applied Remote Sensing*, 9(1):096004.

Chen, J., Huang, Z., Jiang, C., Deng, B. & Long, Y. 2012. An experimental study of changes of beach profile and mean grain size caused by Tsunami-like waves. *Journal of Coastal Research* 28(5):1303-1312.

Coast and shoreline processes. 2016. [Online]. Available:
http://www.ux1.eiu.edu/~cfjps/1300/coasts.html [2016, July 31].

Corbella, S. and Stretch, D.D. 2012. Predicting coastal erosion trends using non-stationary statistics and process-based models. *Coastal Engineering* 70:40-49.

Corey, A.T. 1949. Influence of shape in the fall velocity of sand grains. Master's Thesis. Colorado: Colorado A & M College.

Dally, W. R. 1987. Longshore bar formation: Surfbeat or undertow? *Coastal Sediments* 87 1:71-86.

Dally, W.R. 1980. A numerical model for beach profile evolution. Unpublished thesis. Newark, DE: University of Delaware.

Dalrymple, R.A. & Thompson, W.W. 1976. Study of equilibrium beach profiles. *Coastal Engineering Proceedings*, 1(15):1277-1296.

Daly, C. 2009. Low frequency waves in the shoaling and nearshore zone. Unpublished M.Sc. thesis. Delft: Technical University of Delft.

Daly, C., Roelvink, J.A., van Dongeren, A., van Thiel de Vries, J.S.M. & McCall, R.T. 2010. Short wave breaking effects on low frequency waves, in McKee Smith, J. & Lynett, P. (eds.). *Proceedings of 32nd Conference on Coastal Engineering 2010*. Shanghai, China. 228-240.

Davidson-Arnott, R. 2010. *Introduction to coastal processes and geomorphology*. Cambridge: University Press.

Dean, R.G. 1977. Equilibrium beach profiles: U.S. Atlantic and Gulf coasts. Department of Civil Engineering, Ocean Engineering Report, 12, University of Delaware, Newark.

Dean, R.G. 1987. Coastal sediment processes: Toward engineering solutions, in Kraus, N.C. (ed.). *Coastal Sediments '87: Proceedings of a Specialty Conference on Advances in Understanding of Coastal Sediment Processes*, *New Orleans, Louisiana*. New York: American Society of Civil Engineers. Vol. 1:1-24.

Dean, R.G. 1991. Equilibrium beach profiles: Characteristics and applications. *Journal of Coastal Research*, 7(1):53-84.

Deltares. 2015. *XBEACH Manual*. 2015. [Online]. Available: https://oss.deltares.nl/documents/48999/49476/XBeach_manual_11032015.pdf [2016, July 31].

Denny, M.W. (ed). 2014. Biology and the Mechanics of the Wave-Swept Environment. Princeton, New Jersey: Princeton University Press.

Dronkers, J.J. 2005. *Dynamics of coastal systems*. Hackensack, N.J: World Scientific.

Edelman, T. 1972. Dune erosion during storm conditions, in *Proceedings of the 13th Conference on Coastal Engineering, Vancouver, Canada.* American Society for Civil Engineers 2:1305-1311.

Elgar, S., Gallagher, E.L. & Guza, R.T. 2001. Nearshore Sandbar Migration. *Journal of Geophysical Research: Oceans*, 106(C6):11623-11627.

Fauver, L.A. 2005. Toward Predicting Barrier Island Vulnerability: Simple Models for Dune Erosion. Unpublished Masters Thesis. Florida: University of Florida.

FEMA, 2005. Disaster Declarations for 2005. [Online]. Available: https://www.fema.gov/disasters/grid/year/2005 [2016, July 31].

FEMA. 2002. Appendix D: Guidance for coastal flooding analyses and mapping, in FEMA (ed.). Specifications for flood hazards mapping partners.

Finkl, C.W. 2012. *Coastal hazards*. Netherlands: Springer.

Fredsøe, J. & Deigaard, R. 1992. *Mechanics of coastal sediment transport*. New Jersey: World Scientific.

Gourlay, M. 1980. Beaches: Profiles, processes and permeability, in *Proceedings of the 17th Conference on Coastal Engineering, Sydney, Australia.* 1320-1339.

Grzegorzewski, A.S., Johnson, B.D., Wamsley, T.V. & Rosati, J.D. 2013. Sediment transport and morphology modeling of Ship Island, Mississippi, USA, during storm events. *Coastal Dynamics,* 1505-1516.

Hallermeier, R.J. 1981. Terminal settling velocity of commonly occurring sand grains. *Sedimentology*, 28(6):859–865.

Harrison, W., Norcross, J. J., Pore, N. A., & Stanley, E. M. (1967). Circulation of shelf waters off the Chesapeake Bight. Environmental Science Services Administration Prof. Paper 3: 82pp.

Hattori, M. 2011. Field study on onshore-offshore sediment transport. *Coastal Engineering Proceedings*, 1(18):923-940.

Houston, J. R. 1995. Beach-fill volume required to produce specified dry beach width. Technical Note 11-32, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Howd, P.A. & Birkemeier, W.A., 1987. Beach and nearshore survey data: 1981-1984. Technical Report CERC-87-9, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

International Tsunami Information Center. 2016. *How does tsunami energy travel across the ocean and how far can tsunamis waves reach?* [Online]. Available: http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1164&Itemid=2031 [2016, July 31].

IPCC. 2014. *IPCC Fifth Assessment Report.* [Online]. Available: https://www.ipcc.ch/report/ar5/ [2016, November 18].

Janssen, T.T. & Battjes, J.A. 2007. A note on wave energy dissipation over steep beaches. *Coastal Engineering*, 54:711-716.

Jensen, S.G., Aagaard, T., Baldock, T.E., Kroon, A. & Hughes, M. 2009. Berm Formation and Dynamics on a gently sloping beach; the effect of water level and swash overtopping. *Earth Surface Processes and Landforms*, 34(11):1533-1546.

Kajima, R., Shimizu, T., Maruyama, K., & Saito, S. 1982. Experiments on beach profile change with a large wave flume in *Proceedings of the 18th Conference on Coastal Engineering, Cape Town, South Africa*. 1385-1404.

Kemp, P. H. (1960). The relationship between wave action and beach profile characteristics, in *Proceedings of the 7th Conference on Coastal Engineering, Hague, The Netherlands.* 262-277.

Keulegan, G.H. & Krumbein, W.C. 1949. Stable Configuration of bottom slope in a shallow sea and its bearing on geological processes. *Transactions of American Geophysical Union*, 30(6):855-861.

Knappett, J. & Craig, R.F. 2012. *Craig's soil mechanics*. New York: Spon Press.

Kobayashi, N. (2009). Efficient Wave and Current Models for Coastal Structures and Sediments, in Lynett, P. (ed.). Nonlinear Wave Dynamics. Newark: University of Delaware: World Scientific. 67-87.

Kraus, N.C. & Larson, M. 1988. Beach profile change measured in the tank for large waves 1956-1957 and 1962. Technical Report CERC-88-6, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Kriebel, D.L. (1986). Verification study of dune erosion model. *Shore and beach*, 54(3):13 -21.

Kriebel, D.L. 1982. Beach and dune response to hurricanes. Unpublished thesis. Newark, DE: University of Delaware.

Landberg, L. 2015. *Meteorology for wind energy: An introduction*. Chichester, UK: John Wiley & Sons.

Larson, M. & Kraus, N.C. 1989. SBEACH : Numerical Model for Simulating Storm-Induced Beach Change. Report 1, Emperical Foundation and Model Development. Technical Report CERC-89-9, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Larson, M., Kraus, N.C. & Byrnes, M.R. 1990. SBEACH : Numerical Model for Simulating Storm-Induced Beach Change. Report 2, Numerical Formulation and Model Tests. Technical Report CERC-89-9, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Leatherman, S.P., Zhang, K. & Douglas, B.C. 2000. Sea Level Rise shown to Drive Coastal Erosion. *Transactions American Geophysical Union*, 81(6):55-57.

Lee, G. & Birkemeier, W.A. 1993. Beach and nearshore survey data: 1985-1991. Technical Report CERC-93-3, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS

Li, L. & Huang, Z. 2013. Modeling the change of beach profile under Tsunami waves: A Comparison of Selected Sediment Transport Models. *Earthquake and Tsunami*, 7:1350001.

Lockwood, D. 2016. *Causes of tsunami.* [Online]. Available: http://kidspressmagazine.com/science-for-kids/misc/misc/causes-tsunamis.html [2016 July 31].

Lopatoukhin, L.J., Boukhanovsky, A.V., Chernysheva, E.S. Sergey, E.S. & Ivanov, V. 2004. Hindcasting of wind and wave climate of seas around Russia, in *Proceedings of the 8th Internationsal Workshop on Wave Hindcasting and Forecasting*, Oahu, Hawaii.

Manninen, C. & Gauthier, R. 1999. Living with the lakes–understanding and adapting to Great Lakes water level changes. Great Lakes Commission and U.S. Army Corps of Engineers. 39pp.

Marr, A.D. 2015. *Implementation of an open source numerical model (XBeach) to predict the influence of wave grouping on beach profile evolution* [Online]. Available: http://www.imperial.ac.uk/media/imperial-college/faculty-of-engineering/civil/public/ug/ug-final-year-projects/F01---Alexander-Marr.pdf [2016, August 1].

Masselink, G., Scott, T., Poate, T., Russell, P., Davidson, M. & Conley, D. 2016. The extreme 2013/2014 winter storms: Hydrodynamic forcing and coastal response along the southwest coast of England. *Earth Surface Processes and Landforms*, 41(3):378-391.

Met Office 2016. *Beaufort wind force scale*. [Online]. Available: http://www.metoffice.gov.uk/guide/weather/marine/beaufort-scale [2016, August 1].

McCall, R. 2008. The longshore dimension in dune overwash modelling: Development, verification and validation of Xbeach. Master's Thesis. Delft: Delft University of Technology.

Moore, B.D. 1982. Beach profile evolution in response to changes in water level and wave height. Unpublished thesis. Newark, DE: University of Delaware.

Munk, W. H. 1950. Origin and generation of waves, in *Proceedings of the 1st Conference on Coastal Engineering,* Berkely, California. 1-4.

National Hurricane Center. 2016. *Storm surge overview* [Online]. Available: http://www.nhc.noaa.gov/surge/ [2016, August 1].

Nelson, S.A. 2016. *Tulane university lecture on natural disasters - tsunami* [Online]. Available: http://www.tulane.edu/~sanelson/Natural_Disasters/tsunami.htm [2016, July 31].

NERC British Geological Survey. 2016. *Sea level and coastal changes* [Online]. Available: http://www.bgs.ac.uk/discoveringGeology/climateChange/general/coastal.html?src=topNav [2016, August 1].

Nielsen, P. 2009. *Coastal and estuarine processes*. Singapore: World Scientific.

NOAA. 2016. *Distribution of tidal phases* [Online]. Available: http://co-ops.nos.noaa.gov/images/restfig6.gif [2016, July 31].

Nohara, B. 2007. Governing equations of envelopes created by nearly bichromatic waves on deep water. *Nonlinear Dynamics*, 50(1):49-60.

Okihiro, M., Guza, R.T. & Seymour, R.J. 1992. Bound infragravity waves. *Journal of Geophysical Research: Oceans*, 97(C7):11453-11469.

Pender, D. & Karunarathna, H. 2012. Modeling Beach Profile Evolution - A statistical-process based approach. *Coastal Engineering Proceedings,* 1(33):1–10.

Pender, D. & Karunarathna, H. 2013. A statistical-process based approach for modelling beach profile variability. *Coastal Engineering,* 81:19–29.

Richardson, J.F. and Zaki, W.N., 1997. Sedimentation and fluidisation: Part I. *Chemical Engineering Research and Design*, 75:82-100.

Riesenkamp, M. 2011. Probabilistic modelling of extreme beach erosion using XBeach. Unpublished M.Sc. Thesis. Delft university of Technology & The University of Queensland.

Rijn, L.C.V., 1984. Sediment transport, Part II: Suspended load transport. *Journal of hydraulic engineering*, 110(11):1613-1641.

Roelvink, D., Reniers, A., van Dongeren, A., van Thiel de Vries, J., McCall, R. & Lescinski, J. 2009. Modelling storm impacts on beaches, dunes and barrier islands. *Coastal Engineering* 56:1133–1152.

Roelvink, J.A. & Reniers, A. 1995. *LIP 11D Delta flume experiments: A dataset for profile model validation.* Rotterdam : WL / Delft Hydraulics.

Roelvink, J.A. & Stive, M.J.F. 1989. Bar-generating cross-shore flow mechanisms on a beach. *Journal of Geophysical Research*: *Oceans*, 94(C4):4785-4800.

Roelvink, J.A. 1993. Surf beat and its effect on cross-shore profiles. Unpublished PhD thesis. Delft, The Netherlands: Delft University of Technology.

Rosati, J.D., Wise, R.A., Kraus, N.C. & Larson, M. 1993. SBEACH : Numerical Model for Simulating Storm-Induced Beach Change. Report 3, User's Manual. Technical Report CERC-93-2, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Ruessink, B.G. 2012. Towards a process-based model to predict dune erosion along the Dutch Wadden Coast. *Netherlands Journal of Geosciences*, 91(03):357-372.

Saville, T. 1957. Scale Effects in Two-Dimensional Beach Studies. *Transactions from the 7th General Meeting of the International Association of Hydraulic Research*, 1:A3-1-A3-10.

Schoonees, J.S. & Theron, A.K. 1995. Evaluation of 10 cross-shore sediment transport/ morphological models. *Coastal Engineering*, 25(1):1-41.

Schoonees, J.S. 2016. Diagram of Longshore Current and Sediment Transport. Unpublished class notes, Stellenbosch: University of Stellenbosch.

Schultz, E.F., Wilde, R.H. & Albertson, M.L. 1954. Influence of shape on the fall velocity of sedimentary particle. *Missouri River Division Sedimentation Series Report No. 5*: U.S. Army Corps of Engineers, Omaha, Nabraska USA.

Shi, F., Cai, F., Kirby, J.T. & Zheng, J. 2013. Morphological modeling of a nourished bayside beach with a low tide terrace. *Coastal Engineering*, 78:23-34.

Short, A.D. 1975. Multiple offshore bars and standing waves. *Journal of Geophysical Research*, 80(27):3838-3840.

Siems, S. 2013. *How do high and low weather systems work?* [Online]. Available: http://www.abc.net.au/science/articles/2013/01/31/3679358.htm [2016, August 24].

Smagorinsky, J. 1963. General circulation experiments with the primitive equations. *Monthly Weather Review*, 91(3):99-164.

Smith, J. & Kraus, N.C. 1988. An analytical model of wave-induced longshore current based on power law wave height decay. Miscellaneaus Paper CERC-88-3, Beach Erosion Board, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Soulsby, R. 1997. *Dynamics of marine sands: A manual for practical applications*. London: Thomas Telford.

Steetzel, H.J. 1993. Cross-shore transport during storm surges. Ph.D. Thesis. Delft: Delft University of Technology.

Stive, M.J.F. & Wind, H.G. 1982. A study of radiation stress and set-up in the nearshore region. *Coastal Engineering*, 6:1-25.

Thieler, E.R. & Hammar-Klose E.S. 1999. National assessment of coastal vulnerability to future sea-level rise: Preliminary results for U.S. Atlantic Coast. Open File Report:99-593, U.S. Geological Survey.

Thornton, E.B., Humiston, R.T. & Birkemeier, W. 1996. Bar/trough generation on a natural beach. *Journal of Geophysical Research: Oceans*, 101(C5):12097-12110.

Trujillo, A.P. & Thurman, H.V. 2007. Chapter 9: *Tides, Essentials of oceanography*. New Jersey, Pennsylvania State University: Prentice Hall. 276-299.

Turner, I.L., Harley, M.D., Short, A.D., Simmons, J.A., Bracs, M.A., Phillips, M.S. & Splinter, K.D. 2016. A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen, Australia. *Scientific Data* 3:160024.

UCAR Center for Science Education. 2016. *The highs and lows of air pressure* [Online]. Available: http://scied.ucar.edu/shortcontent/highs-and-lows-air-pressure [2016, August 1].

USACE. 2010. *Beach Nourishment Project, Town of Nags Head: Environmental Impact Statement*.

Van Dorn, W.G. 1974. *Oceanography and seamanship*. New York:Dodd, Mead & Company.

Van Rijn, L.C. 1984. Sediment Transport, Part II: Suspended Load Transport. *Journal of Hydraulic Engineering*, ASCE, 110(11).

van Rijn, L.C. 2007. Unified view of sediment transport by currents and waves. I: Initiation of motion, bed roughness, and bed-load transport. *Journal of Hydraulic Engineering*, 133(6):649-667.

Van Rijn, L.C. 2008. *Beach and Dune Erosion due to Storms* [Online]. Available: http://www.leovanrijn-sediment.com/papers/P6-2008a.pdf [2016, August 1].

Van Rijn, L.C., Walstra, D.J.R., Grasmeijer, B., Sutherland, J., Pan, S. & Sierra, J.P. 2003. The predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based profile models. *Coastal Engineering*, 47(3):295-327.

Van Thiel de Vries, J.S.M. 2009. Dune erosion during storm surges. Doctoral Thesis. Delft: iOS Press.

Velegrakis, A.F. 2012. Beach Modelling III: Morphodynamic models – Description. Unpublished class notes. Mytilene, Greece: University of Aegean.

Vellinga, P. 1982. Beach and Dune Erosion during Storm Surges. *Coastal Engineering*, 6(4):361-387.

Vicinanza, D., Baldock, T., Contestabile, P., Alsina, J., Cáceres, I., Brocchini, M., Conley, D., Andersen, T.L., Frigaard, P. and Ciavola, P. (2011). Swash zone response under various wave regimes. *Journal of Hydraulic Research*, 49:55-63.

Vousdoukas, M.I. 2013. Beach Erosion and Recovery – A Modeling and Measuring Challenge, 9. FZK Kolloquium “Modellierung im Seebau und Küsteningenieurwesen”, Forschungszentrum Küste, Hannover.

Vousdoukas, M.I., Ferreira, Ó., Almeida, L.P. & Pacheco, A. 2012. Towards reliable storm-hazard forecasts: XBeach calibration and its potential application in an operational early-warning system. *Ocean Dynamics*, 61: 1001-1015.

Warren, B. & Wunsch, C. 2007. Evolution of physical oceanography. Massachusetts: Massachusetts Institute of Technology.

Wikipedia. 2016*. Infra-gravity waves* [Online]. Available: https://en.wikipedia.org/wiki/Infra-gravity_wave [2016 July 31].

Williams,J.J., de Alegría-Arzaburu, A.R., McCall, R.T. & Van Dongeren, A.P. 2012. Modelling gravel barrier profile response to combined waves and tides using XBeach: Laboratory and field results. *Coastal Engineering* 63: 62–80.

Woods Hole Oceanographic Institution. 2016. *Predicting potential disasters* [Online]. Available: https://www.whoi.edu/page.do?pid=83337&tid=3622&cid=80626 [2016 July 31].

Wunderground. 2016. *World storm surge records* [Online]. Available: https://www.wunderground.com/hurricane/surge_world_records.asp [2016 August 1].

Yang, C.T. 1996. *Sediment Transport: Theory and Practice*. McCraw-Hill. New York.

Yang, C.T. 2003. *Sediment transport : Theory and practice*. Malabar, Florida: Krieger Publishing Company.

APPENDIX A: WATER LEVEL VARIATION SENSITIVITY

Appendix A-1: Model Runs to Evaluate Sensitivity to Water Level Variation

Run	Wave Height (m)	Wave Period (s)	Water Elevation Above MSL (m)	Duration (h)
1.1	0.8	6	+5	12
1.2	0.8	6	+4	12
1.3	0.8	6	+3	12
1.4	0.8	6	+2	12
1.5	0.8	6	+1	12
1.6	0.8	6	0	12
1.7	0.8	6	-1	12
1.8	0.8	6	-2	12
1.9	0.8	6	-3	12
1.10	0.8	6	-4	12
1.11	0.8	6	-5	12
2.1	3	12	+5	12
2.2	3	12	+4	12
2.3	3	12	+3	12
2.4	3	12	+2	12
2.5	3	12	+1	12
2.6	3	12	0	12
2.7	3	12	-1	12
2.8	3	12	-2	12
2.9	3	12	-3	12
2.10	3	12	-4	12
2.11	3	12	-5	12
3.1	6	16	+5	12
3.2	6	16	+4	12
3.3	6	16	+3	12
3.4	6	16	+2	12
3.5	6	16	+1	12
3.6	6	16	0	12
3.7	6	16	-1	12
3.8	6	16	-2	12
3.9	6	16	-3	12
3.10	6	16	-4	12
3.11	6	16	-5	12

Appendix A-2: Water Level Sensitivity Runs Model Configuration/Parameter Setups

```
*********************************************************

*  SBEACH model configuration file:    WLD1_1.CFG       *

*********************************************************

A---------------------------  MODEL SETUP  ------------------------------A

A.1  RUN TITLE: TITLE

    WLD1: +5m MSL Water Elevation, Wave condition 1

A.2  INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS

    1

A.3  TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY

    RELATIVE TO INITIAL PROFILE: NDX, XSTART

    766      -550.00

A.4  GRID TYPE (CONSTANT=0, VARIABLE=1): IDX

    0

A.5  COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6  CONSTANT GRID CELL WIDTH: DXC

    1.5

A.7  COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8  NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID

    2

A.9  GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD

    TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)

    2, 99  1, 899


A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT

    720       1.0
```

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR

1

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)

480

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP

0

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH WILL BE DETERMINED): ELV1, ELV2, ELV3

15.00 5.00 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED EDP1, EDP2, EDP3, REFELV

15.00 5.00 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K

1.75E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS

0.002000

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM

0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC

20.00

B---------------------- WAVES/WATER ELEVATION/WIND -----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE

1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE

0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T

0.80 6.00

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV

60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG

0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN

0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG

0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS

0.0

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND

0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC

7878 20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV

0

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV

5.00

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV

60.00

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND

0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND

0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND

0.00

C------------------------------ BEACH ----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN

1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,

LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,

END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,

XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS

0.30

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50

0.25

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX

20.00

D------------------------------ BEACH FILL --------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL

0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE

TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START

AND END OF BEACH FILL: NFILL

0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE

INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E-------------------------- SEAWALL/REVETMENT ----------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL

0

E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.

E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL

0.00

E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL

0

E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.

E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION

AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES

FAILURE: PEFAIL, WEFAIL,HFAIL

0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F

----------------------------------- END ------------------------------------

%%% XBeach parameter settings input file %%%

%%% date: 03-Aug-2016 12:00 %%%

%%% function: xb_write_params %%%

%%% Grid parameters %%%

gridform = xbeach

depfile = DepSeaLevel.dep

posdwn = -1

alfa = 0

dx = 1.5

dy = 0

nx = 765

ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90

thetamax = +90

dtheta = 10

thetanaut = 0

%%% Model time %%%

tstart = 0

tstop = 43200

tintg = 60

tintp = 60

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rho = 1025

g = 9.81

D50 = 0.00025

rhos = 2650

por = 0.3

%%% Flow boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

front = abs_1d

back = abs_1d

left = 0

right = 0

%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tideloc = 0

zs0 = 5

%%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% %

instat = 0

Hrms = 0.8

Trep = 6

lwave = 0

%%% Morphology Conditions %%

morfac = 1

morstart = 0

%%% Output variables %%%

outputformat = netcdf

nglobalvar = 6

zb
zb0
zs
H
hh
Qb

nmeanvar = 3

H
hh
zs

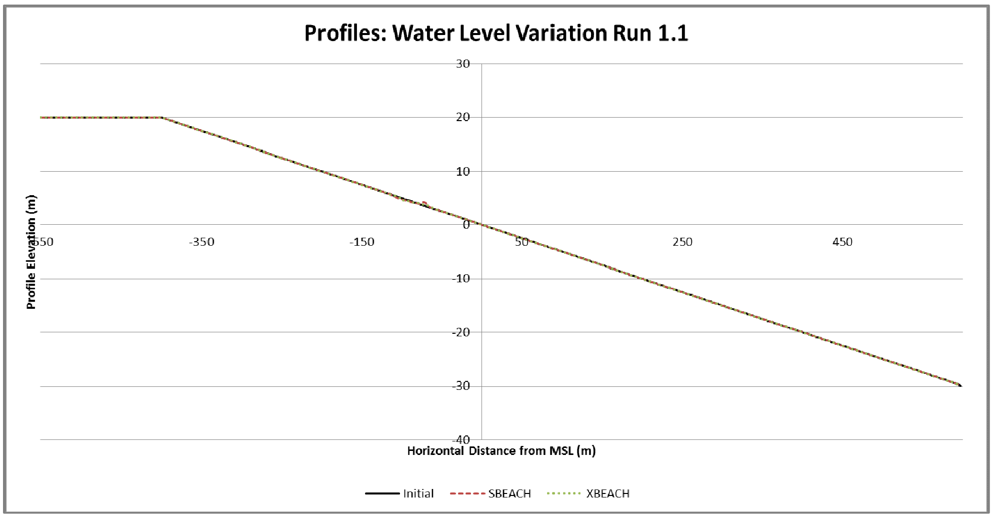
DUNERULE

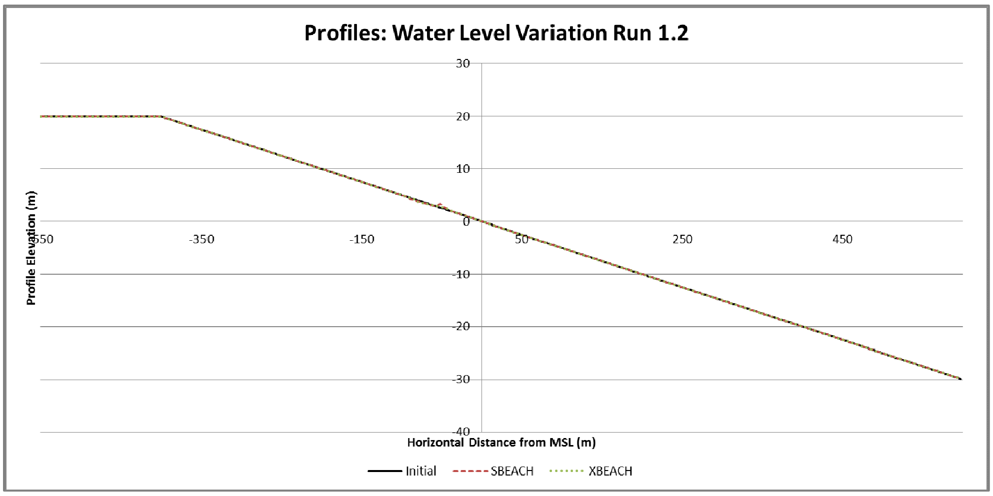
Input values in RED; computed values blue

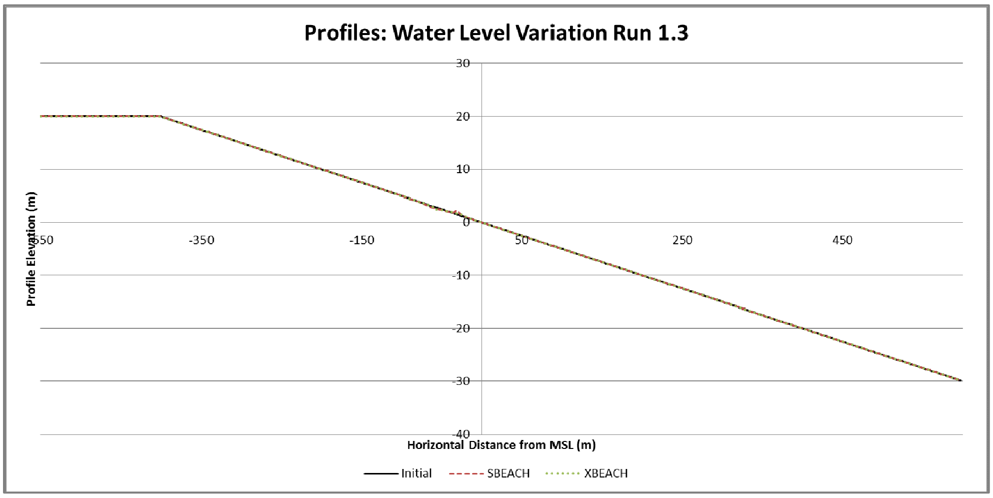
Case	Sediment Size d50 (m)	Surf Zone Slope tanb (-)	Offshore Wave Height Hs,o (m)	Wave Period Tp (s)	Wave Angle to Normal θ (deg)	Storm Surge Level (including wave setup and tide) SSL (m)	Dune height above MSL B (m)	Time t (h)
1.1	0.000250	0.0500	0.8	6.0	0	5	20	12

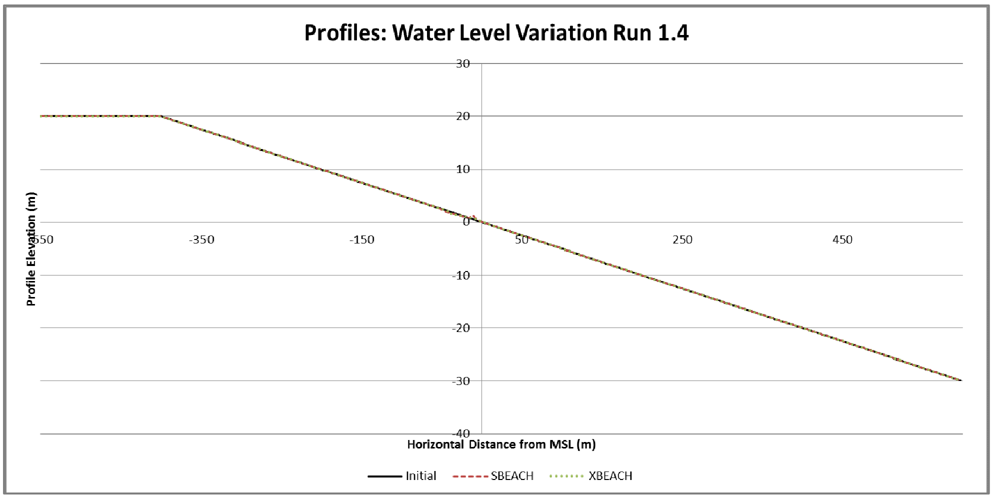
Dune Recession Van Rijn					
Erosion Volume After 5h (m3/m)	Mean Recession After 5h (m)	Maximum Recession After 5h (m)	Erosion Volume After t hours (m3/m)	Mean Recession After t hours (m)	Maximum Recession After t hours (m)
43.5062	2.90041619	4.35062429	51.8315061	3.45543374	5.18315061

Appendix A-3: Water Level Variation Model Sensitivity Runs Output

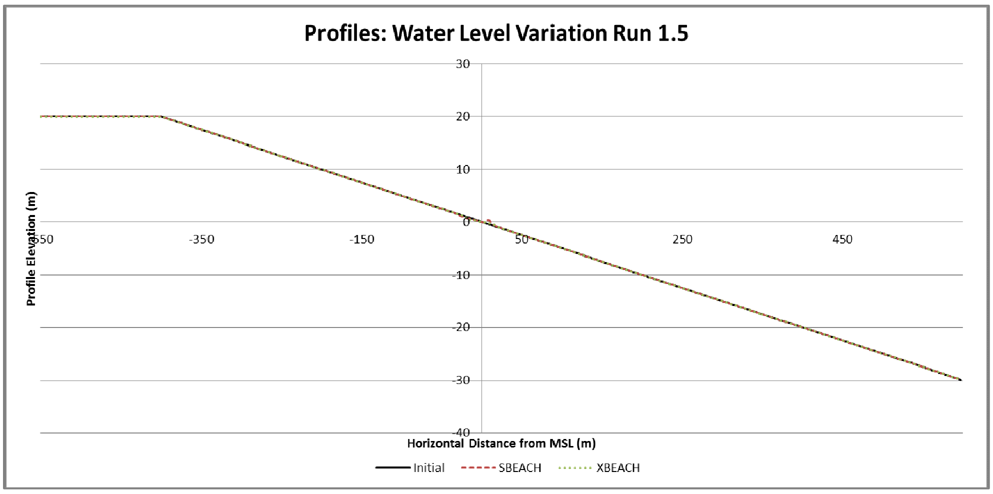




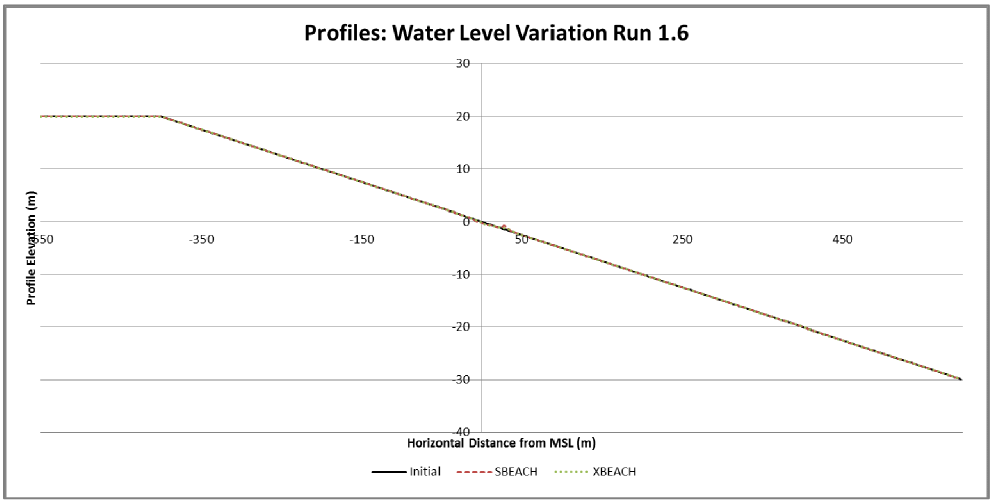




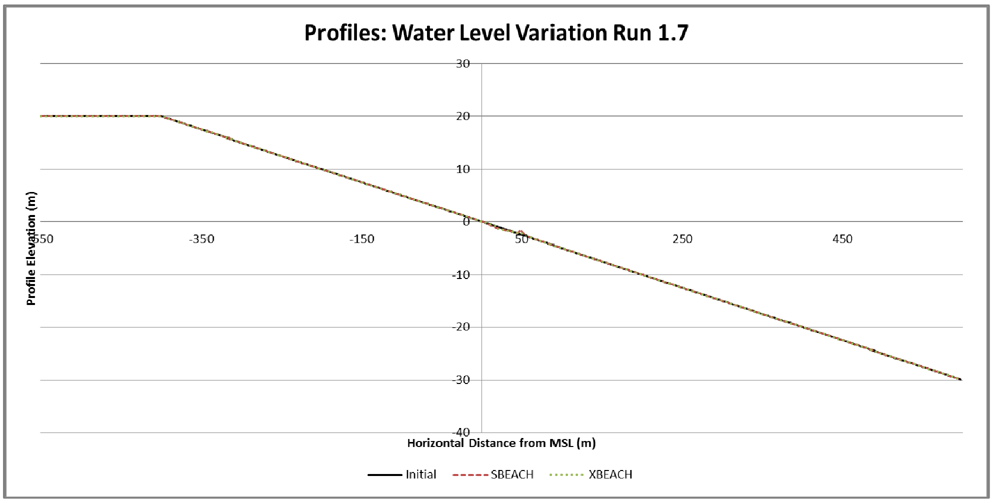
Profiles: Water Level Variation Run 1.4
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH



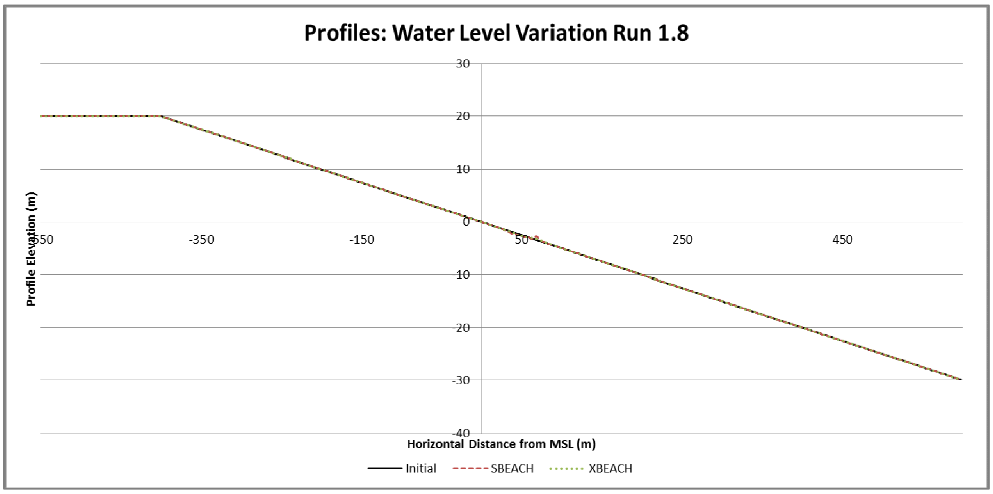
Profiles: Water Level Variation Run 1.5
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH



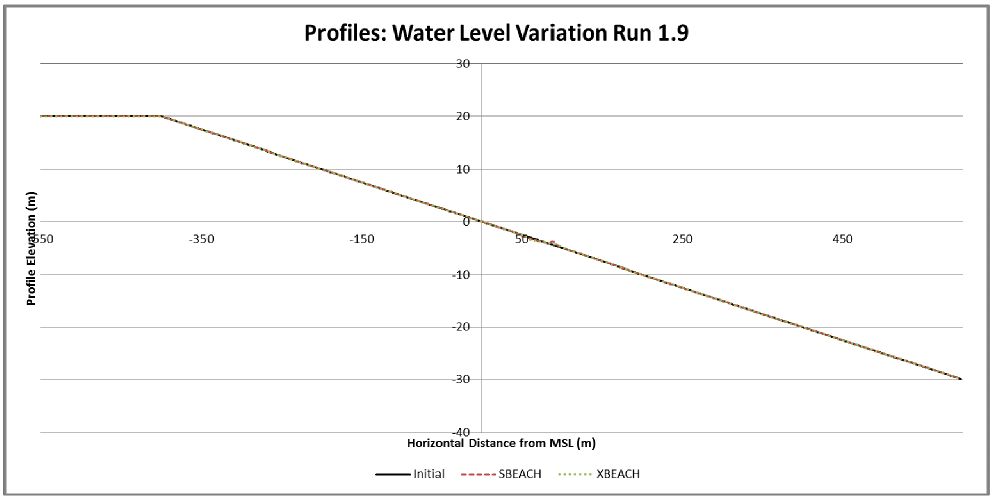
Profiles: Water Level Variation Run 1.6
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH



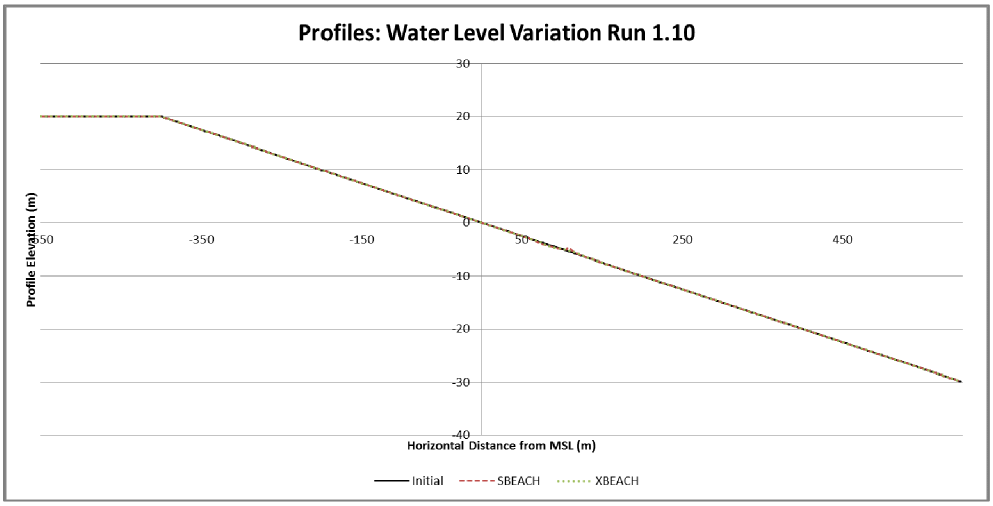
Profiles: Water Level Variation Run 1.7
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

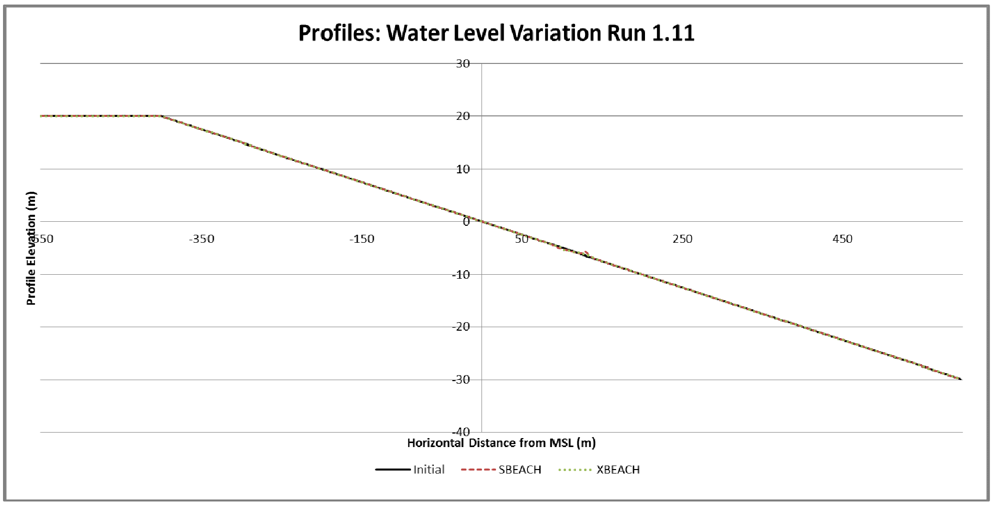


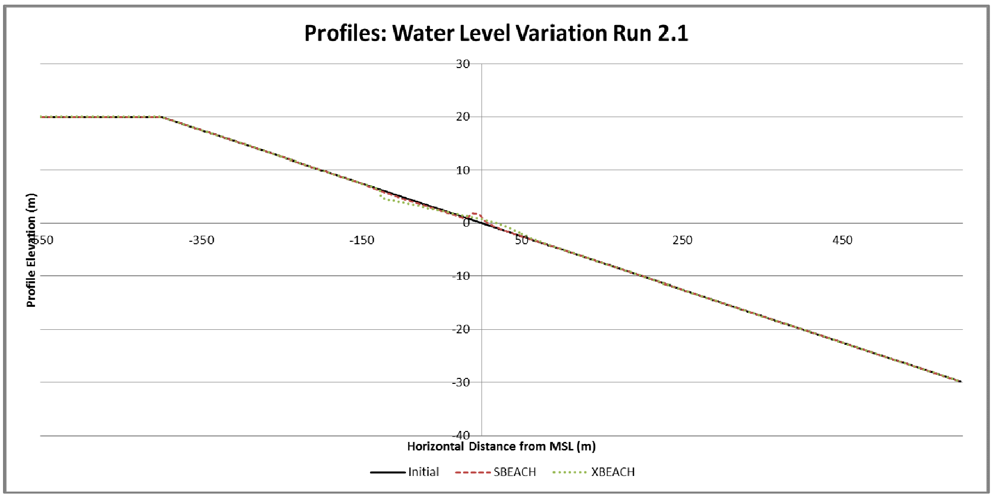
Profiles: Water Level Variation Run 1.8
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

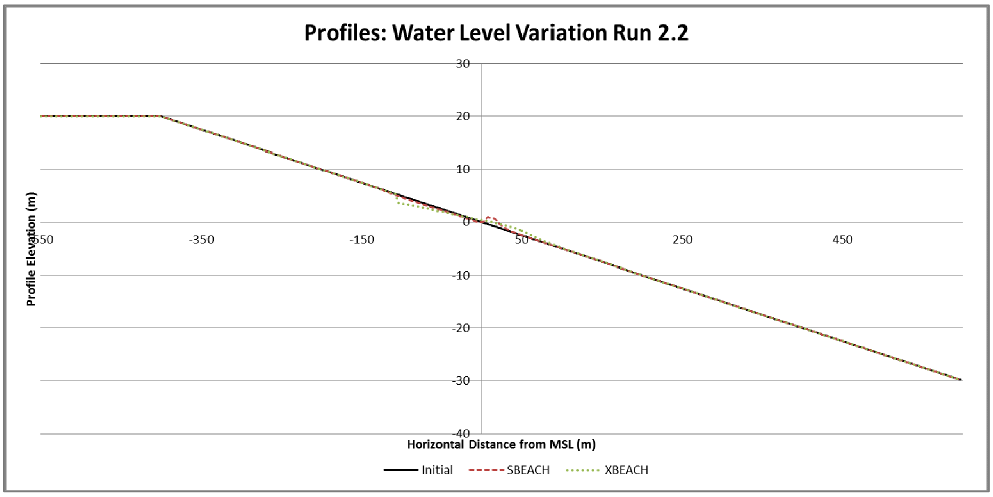


Profiles: Water Level Variation Run 1.9
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

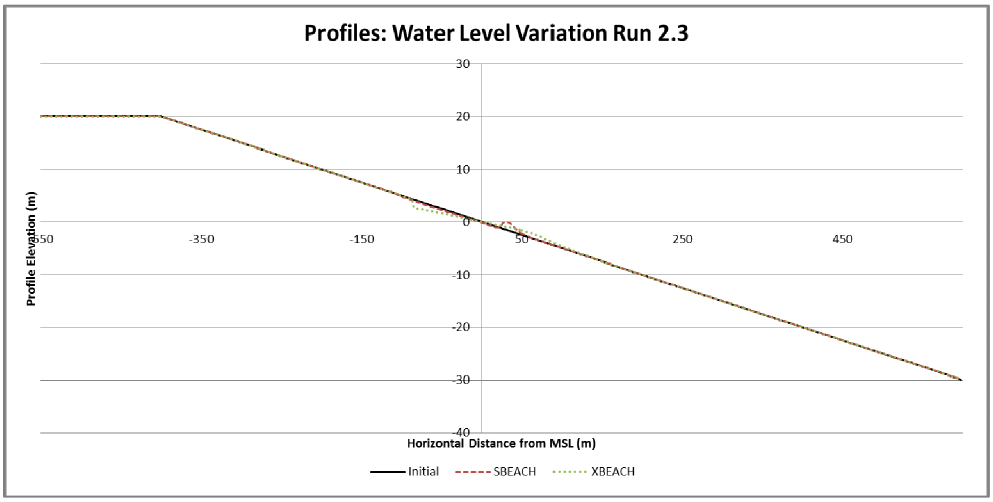

Profiles: Water Level Variation Run 1.10
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 1.11
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

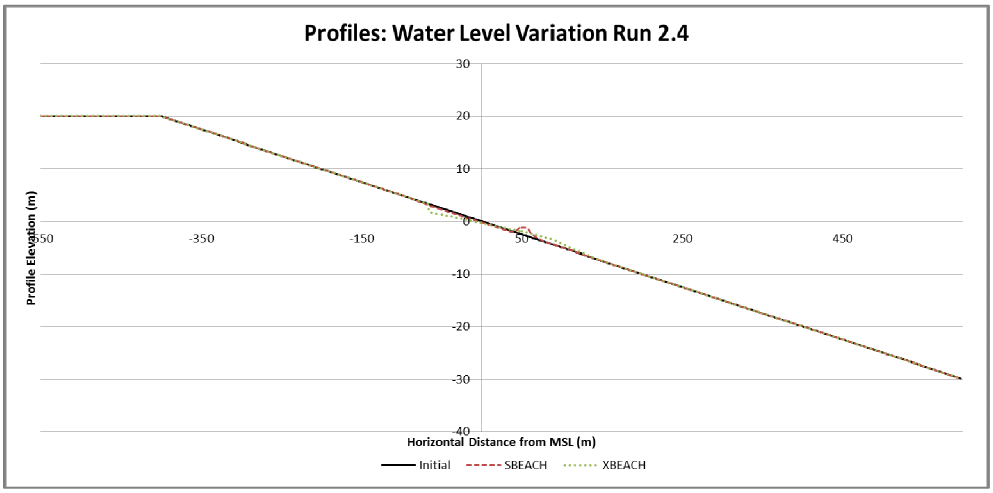

Profiles: Water Level Variation Run 2.1
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH



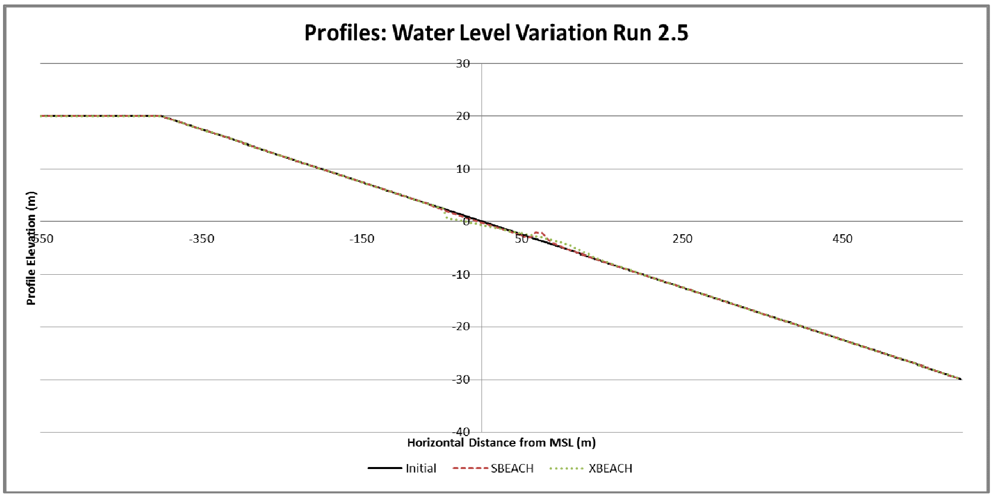
Profiles: Water Level Variation Run 2.2
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

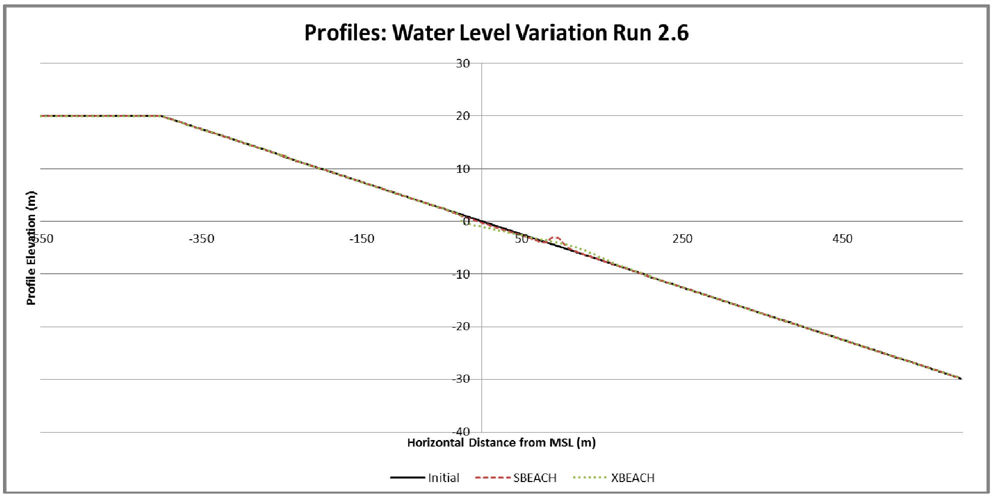


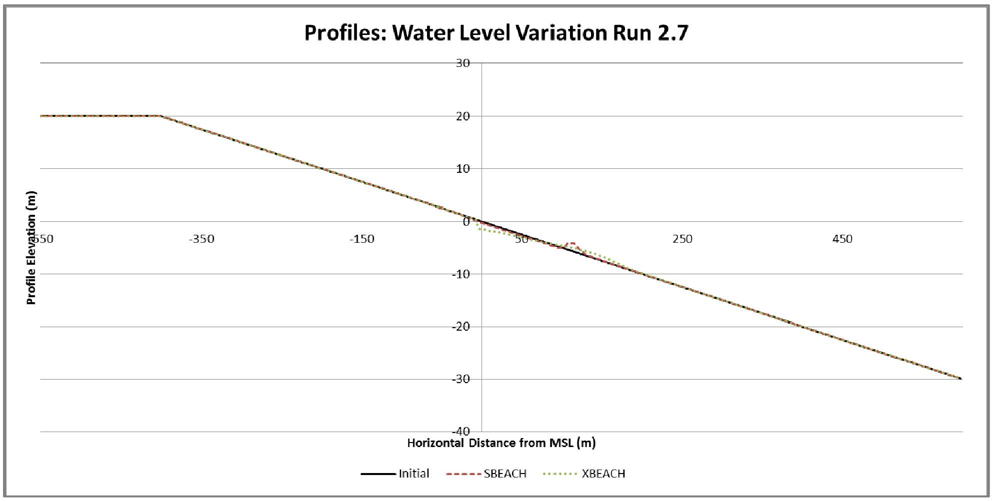
Profiles: Water Level Variation Run 2.3
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

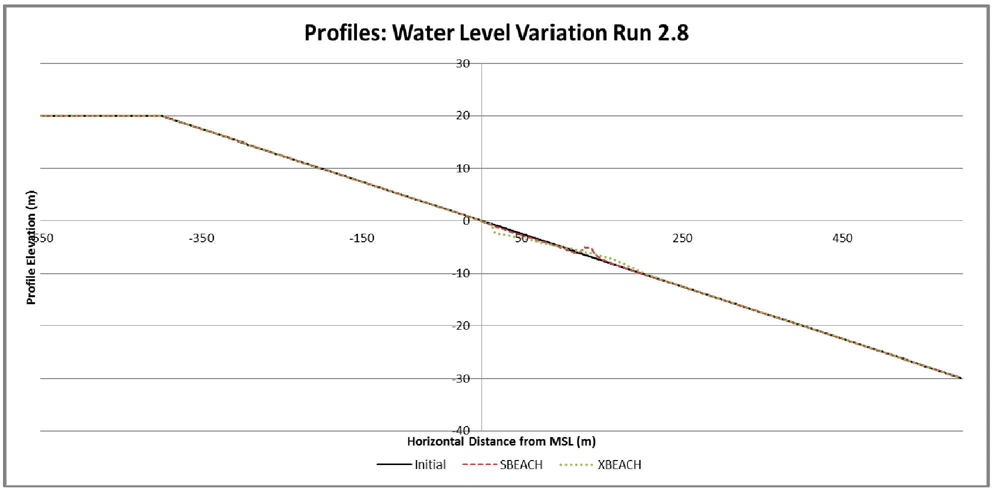


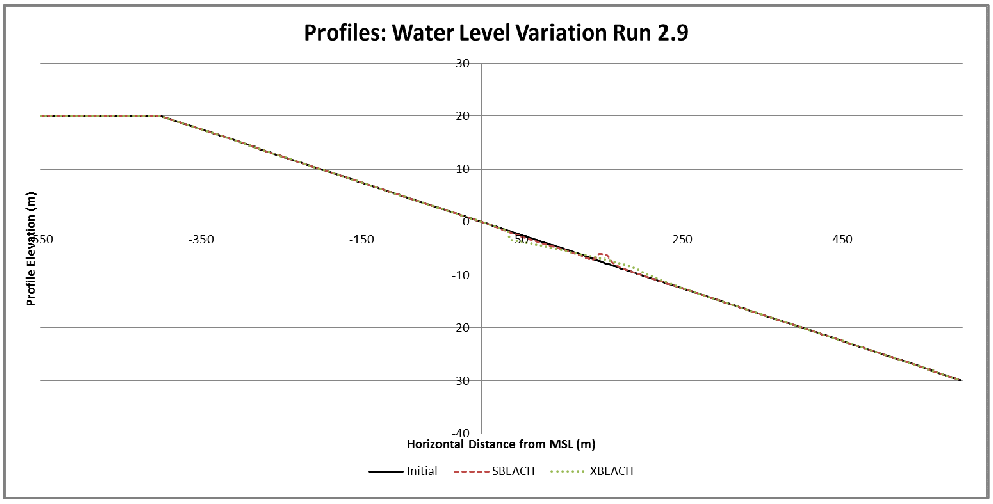
Profiles: Water Level Variation Run 2.4
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

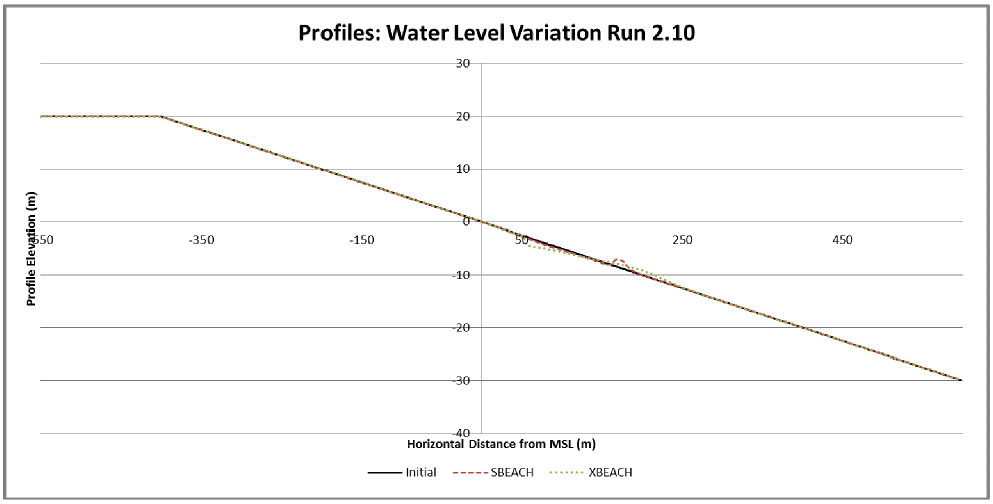

Profiles: Water Level Variation Run 2.5
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

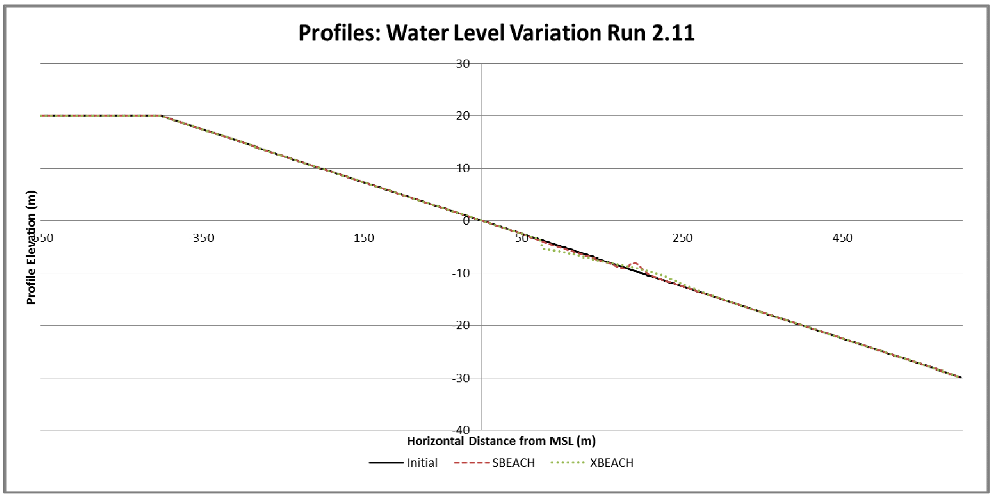

Profiles: Water Level Variation Run 2.6
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 2.7
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

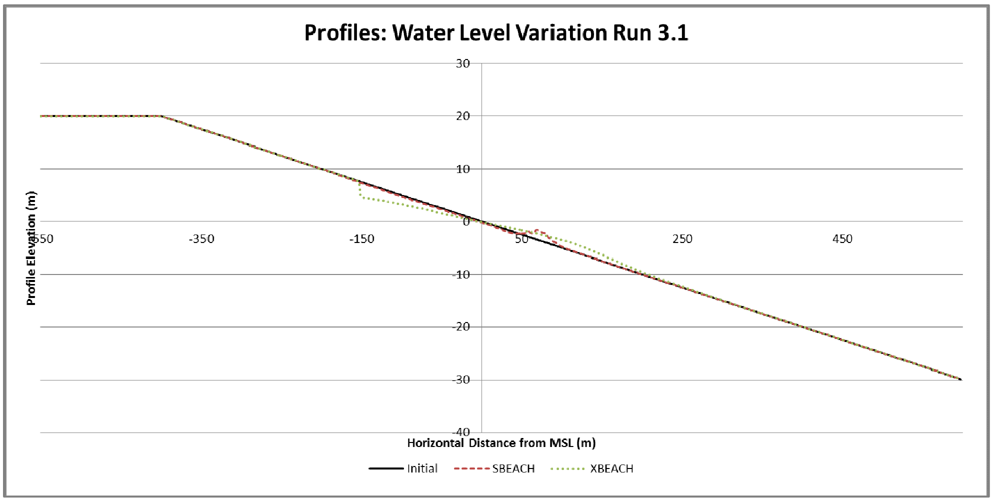

Profiles: Water Level Variation Run 2.8
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 2.9
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

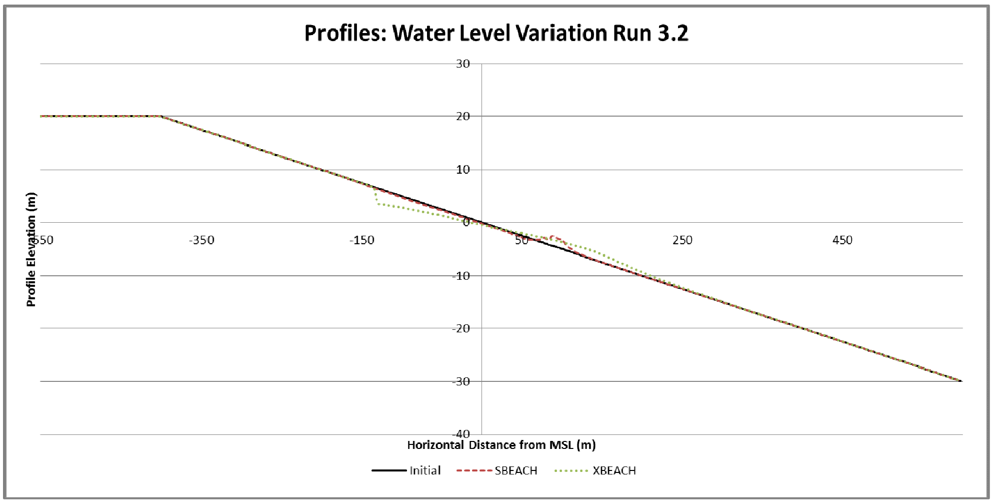

Profiles: Water Level Variation Run 2.10
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH



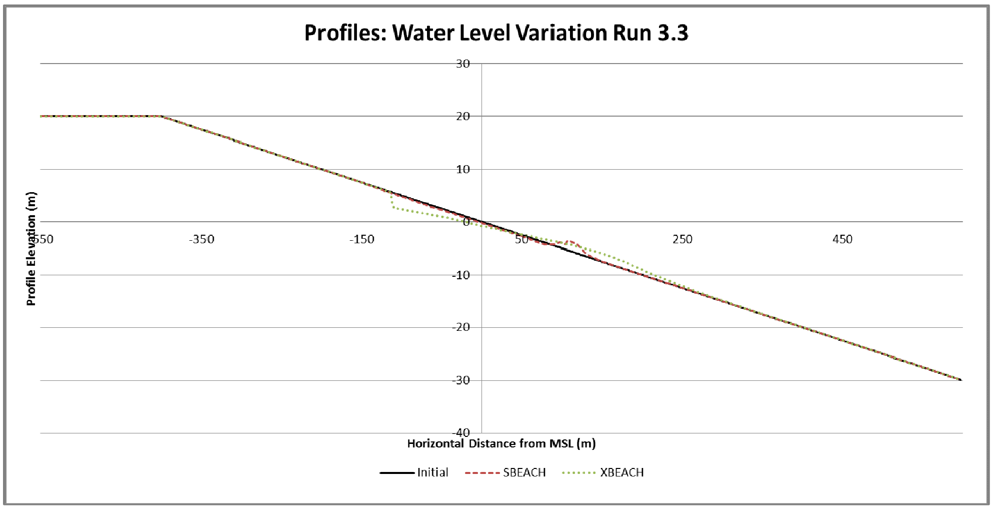
Profiles: Water Level Variation Run 2.11
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

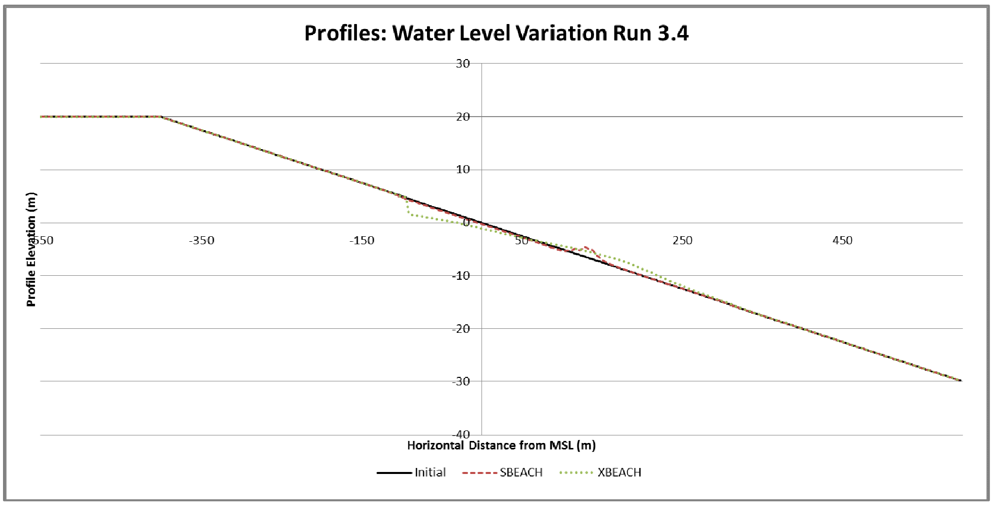


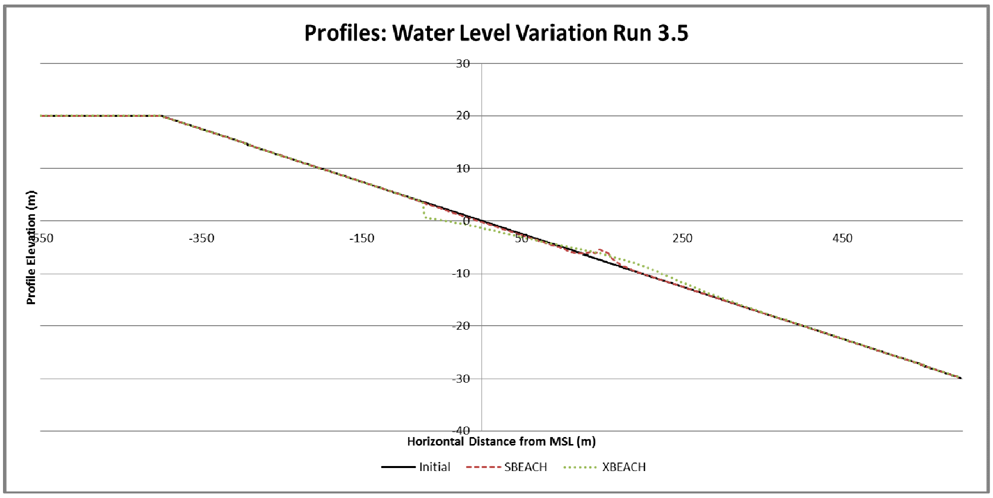
Profiles: Water Level Variation Run 3.1
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

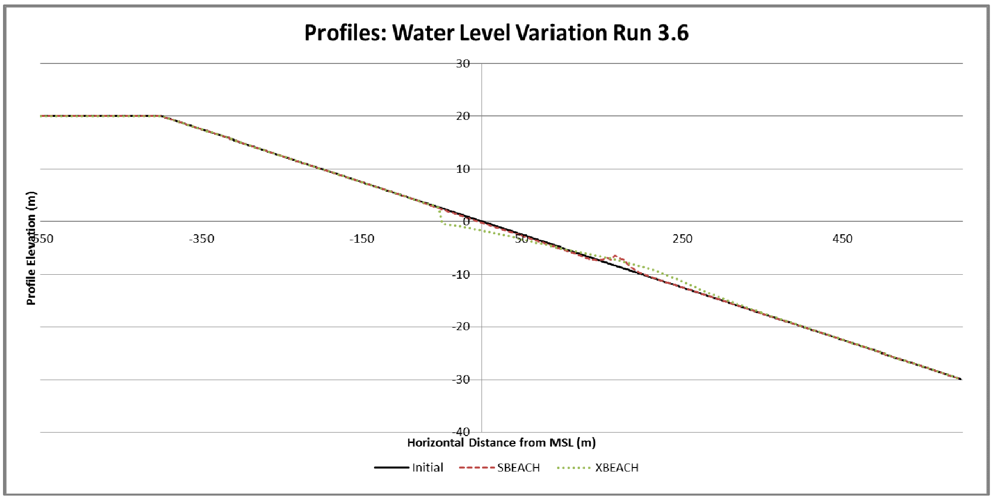


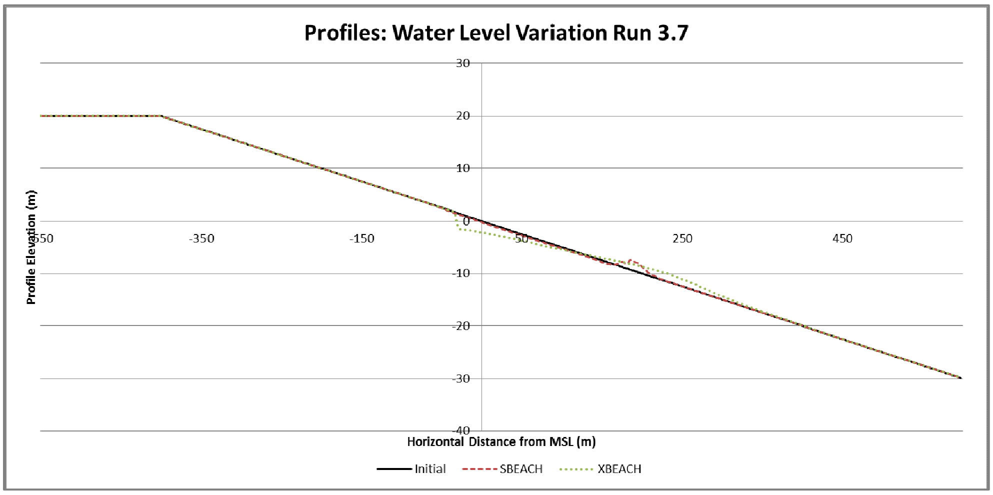
Profiles: Water Level Variation Run 3.2
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

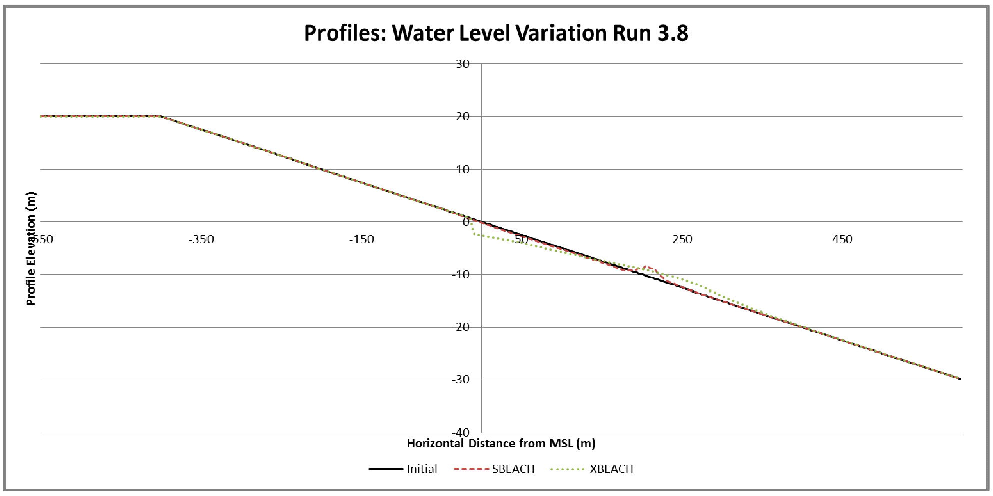

Profiles: Water Level Variation Run 3.3
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

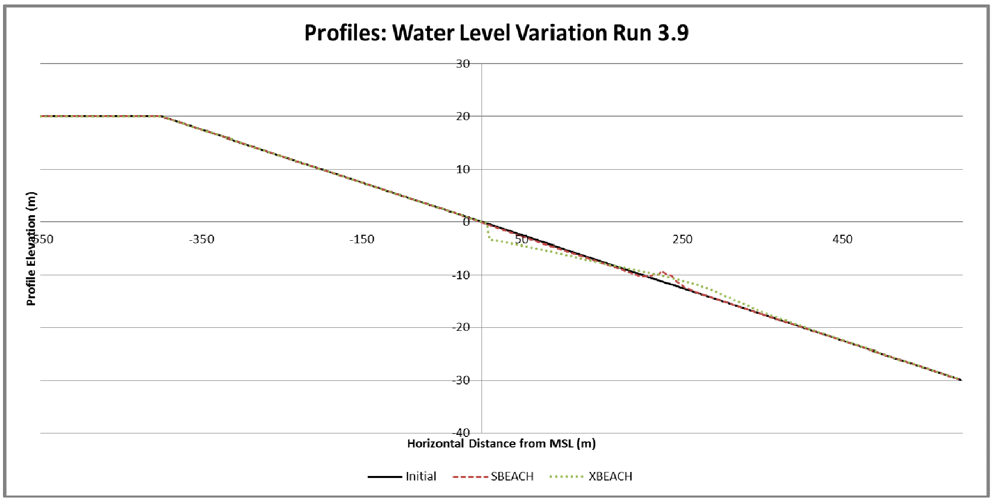

Profiles: Water Level Variation Run 3.4
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

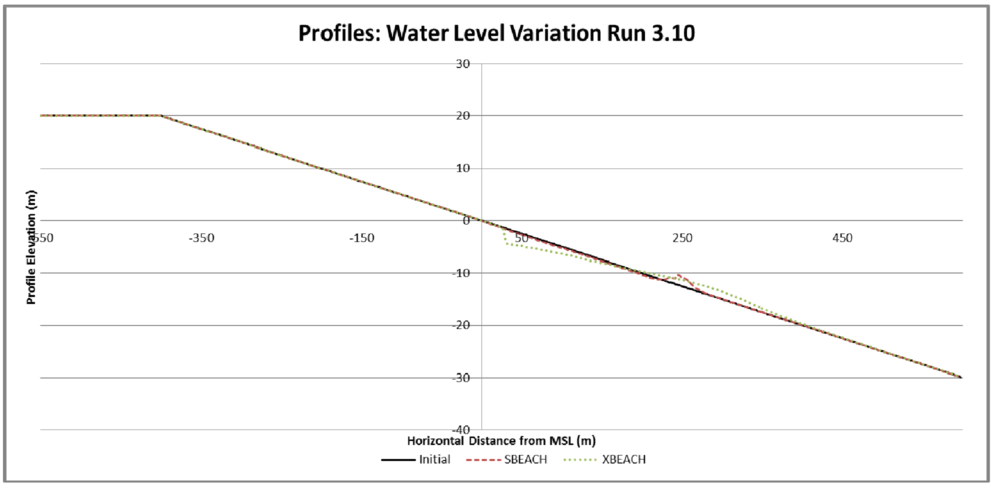

Profiles: Water Level Variation Run 3.5
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

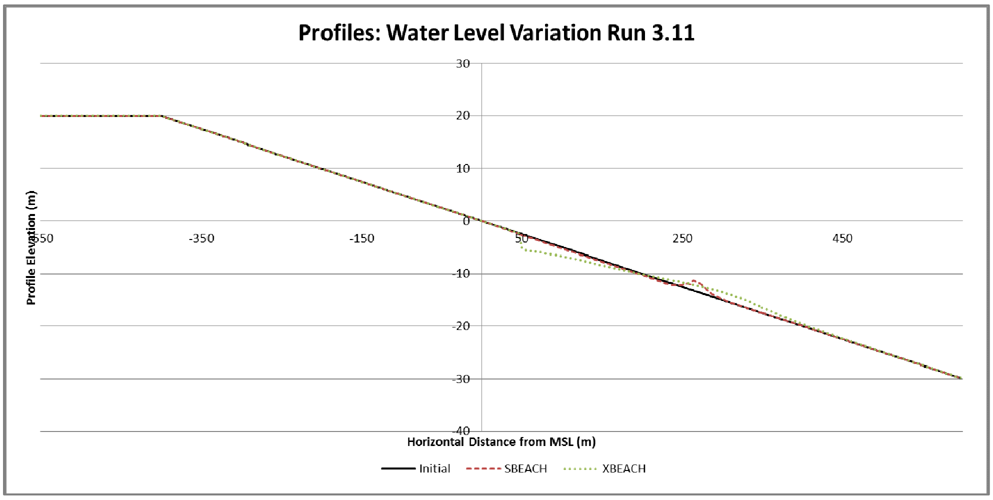

Profiles: Water Level Variation Run 3.6
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 3.7
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 3.8
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 3.9
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 3.10
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Water Level Variation Run 3.11
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

DUNERULE

Input values in RED; computed values blue

Case	Sediment Size d50 (m)	Surf Zone Slope tanb (-)	Offshore Wave Height Hs,o (m)	Wave Period Tp (s)	Wave Angle to Normal θ (deg)	Storm Surge Level (including wave setup and tide) SSL (m)	Dune height above MSL B (m)	Time t (h)
1.1	0.000250	0.0500	0.8	6.0	0	5	20	12

Dune Recession Van Rijn					
Erosion Volume After 5h (m3/m)	Mean Recession After 5h (m)	Maximum Recession After 5h (m)	Erosion Volume After t hours (m3/m)	Mean Recession After t hours (m)	Maximum Recession After t hours (m)
43.5062	2.90041619	4.35062429	51.8315061	3.45543374	5.18315061

Appendix A-4: Water Level Sensitivity Comparison Parameters

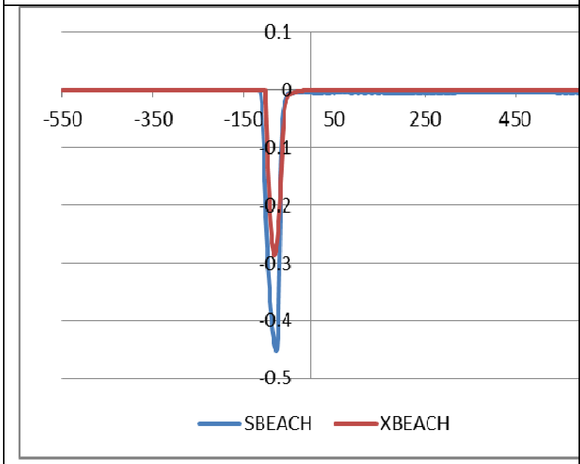
Run	Absolute Displaced Sediment Volumes (m^3/m)			Eroded Volume of Sediment Above Water Level (m^3/m)			Shoreline Recession (m)		
	SB	XB	DR	SB	XB	DR	SB	XB	DR
1.1	11.58	6.90	-	2.62	0.28	51.83	4.83	0.38	5.18
1.2	11.49	7.05	-	2.57	0.17	38.68	5.06	0.90	3.63
1.3	11.42	7.18	-	2.60	0.26	26.61	4.88	1.06	2.35
1.4	11.06	6.90	-	2.62	0.29	15.71	4.83	1.26	1.31
1.5	11.07	7.08	-	2.55	0.13	6.38	4.93	0.78	0.50
1.6	10.98	7.23	-	2.61	0.26	0.00	4.88	1.06	0.00
1.7	11.09	6.93	-	2.65	0.29	-	4.83	1.29	-
1.8	11.34	7.07	-	2.56	0.14	-	4.93	0.79	-
1.9	11.43	7.21	-	2.59	0.26	-	4.88	1.08	-
1.10	11.60	6.97	-	2.65	0.30	-	4.88	1.28	-
1.11	11.76	7.12	-	2.60	0.18	-	5.06	0.92	-
2.1	58.01	132.06	-	10.21	34.03	141.95	5.81	25.36	14.19
2.2	58.07	131.99	-	10.23	34.09	105.92	5.81	24.77	9.93
2.3	57.84	131.91	-	10.22	33.94	72.87	5.63	25.05	6.43
2.4	57.62	131.81	-	10.22	33.99	43.02	5.81	25.32	3.58
2.5	57.59	131.65	-	10.18	33.87	17.47	5.68	24.64	1.38
2.6	57.38	131.39	-	10.19	33.85	0.00	5.63	25.04	0.00
2.7	57.44	131.19	-	10.24	33.88	-	5.81	25.22	-
2.8	57.44	131.01	-	10.17	33.74	-	5.68	24.61	-
2.9	57.56	130.69	-	10.13	33.68	-	5.63	25.03	-
2.10	57.62	130.36	-	10.18	33.69	-	5.81	25.05	-
2.11	57.53	130.06	-	10.19	33.69	-	5.81	24.73	-
3.1	105.81	428.81	-	15.49	121.51	231.80	5.44	51.01	23.18
3.2	105.57	427.50	-	15.51	121.36	172.96	5.49	50.25	16.22
3.3	105.47	426.23	-	15.58	120.92	118.99	5.44	50.53	10.50
3.4	105.02	424.80	-	15.52	120.72	70.24	5.44	50.53	5.85
3.5	104.84	423.40	-	15.42	120.27	28.53	5.30	50.06	2.25
3.6	104.57	421.92	-	15.43	120.03	0.00	5.44	50.51	0.00
3.7	104.76	420.38	-	15.44	119.83	-	5.44	50.02	-
3.8	104.61	418.90	-	15.30	119.35	-	5.30	50.04	-
3.9	104.27	417.40	-	15.23	119.04	-	5.44	50.46	-
3.10	103.74	415.94	-	15.17	118.87	-	5.44	49.69	-
3.11	103.52	414.70	-	15.26	118.73	-	5.49	50.16	-

Appendix A-5: Water Level Sensitivity Sediment Transport Rate Distributions

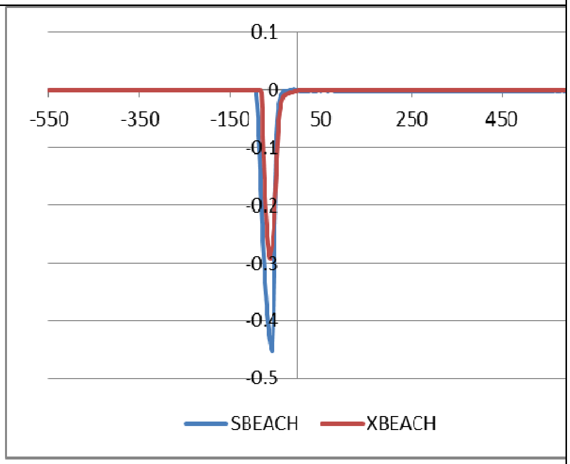
Sediment Transport Rate (m^3/m/h)

Distance from Mean Sea Level (m)

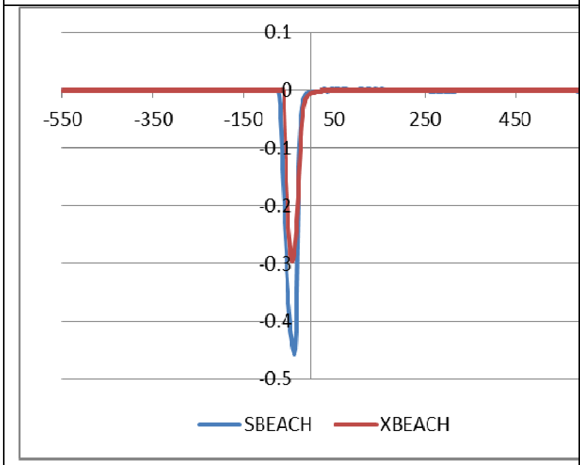
Run 1.1



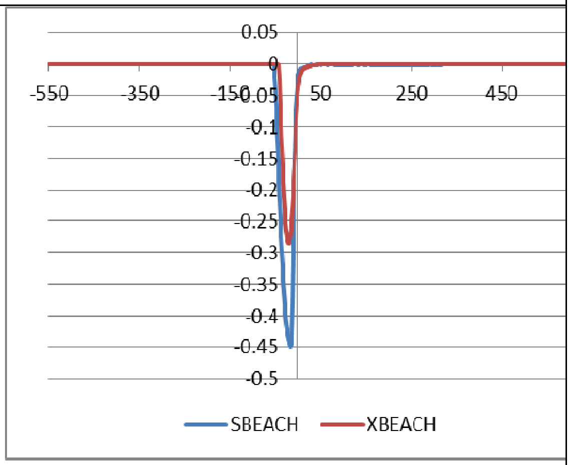
Run 1.2



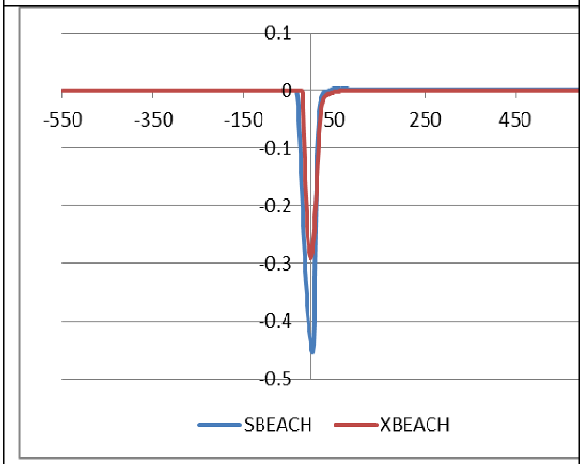
Run 1.3



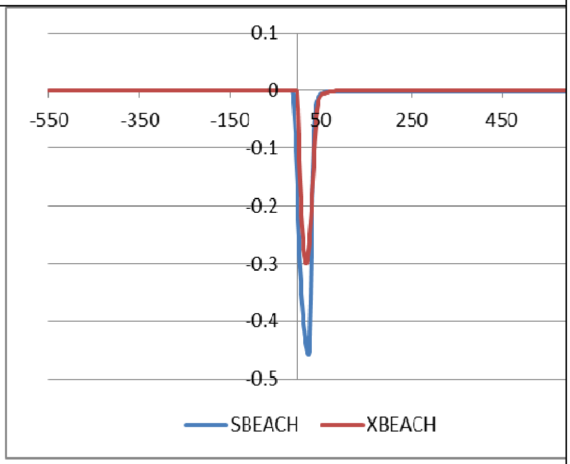
Run 1.4



Run 1.5



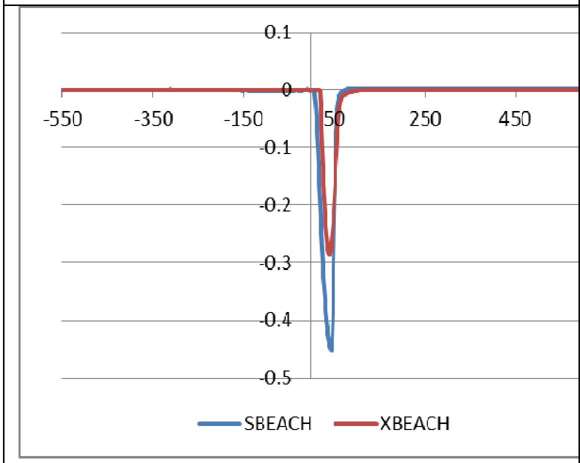
Run 1.6



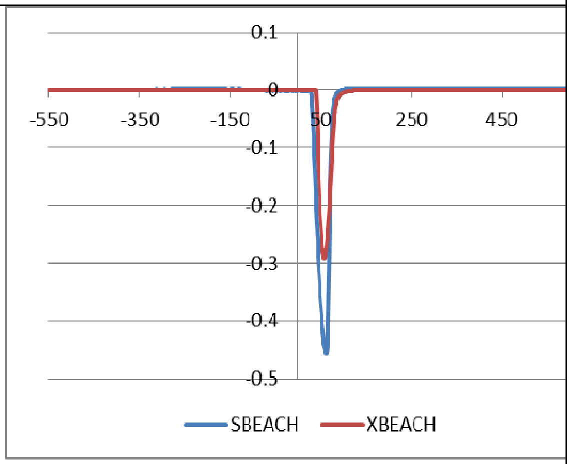
Distance from Mean Sea Level (m)

Sediment Transport Rate ($m^3/m/h$)

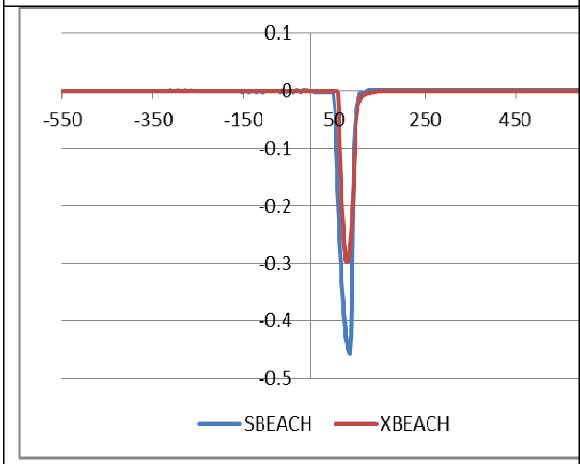
Run 1.7



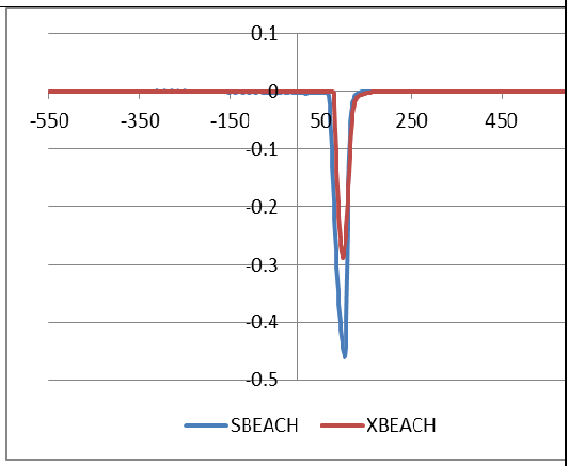
Run 1.8



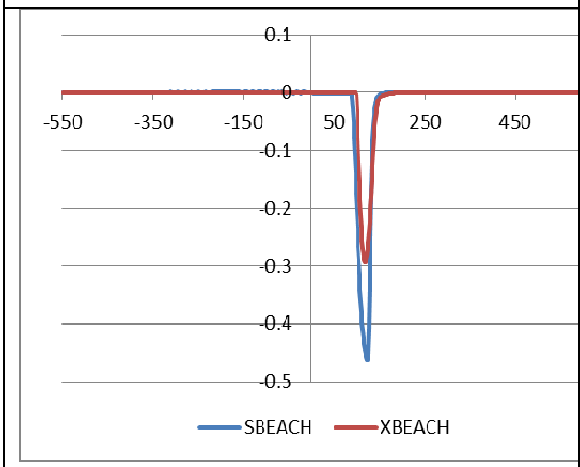
Run 1.9



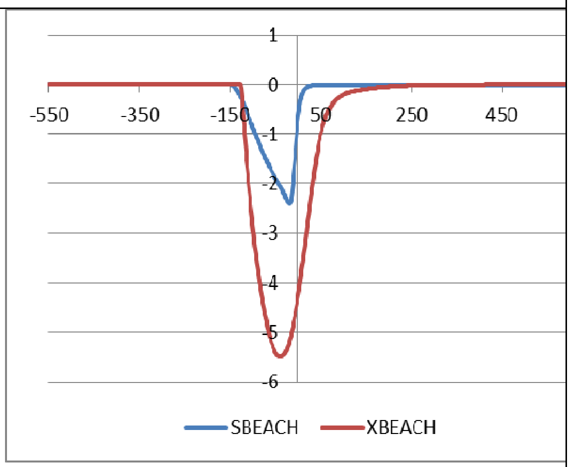
Run 1.10



Run 1.11



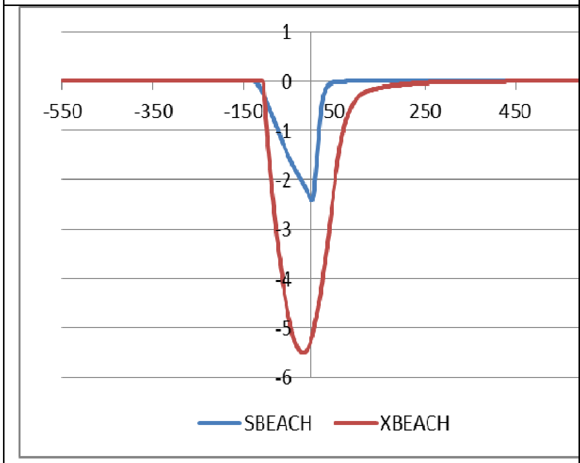
Run 2.1



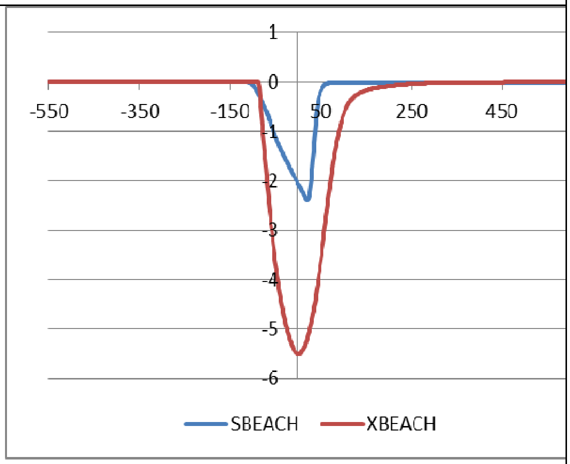
Sediment Transport Rate ($m^3/m/h$)

Distance from Mean Sea Level (m)

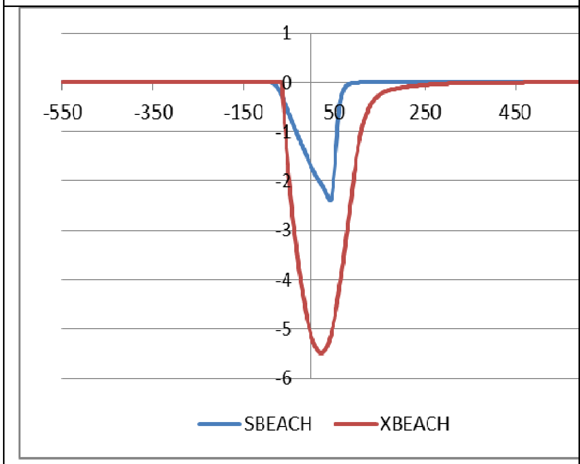
Run 2.2



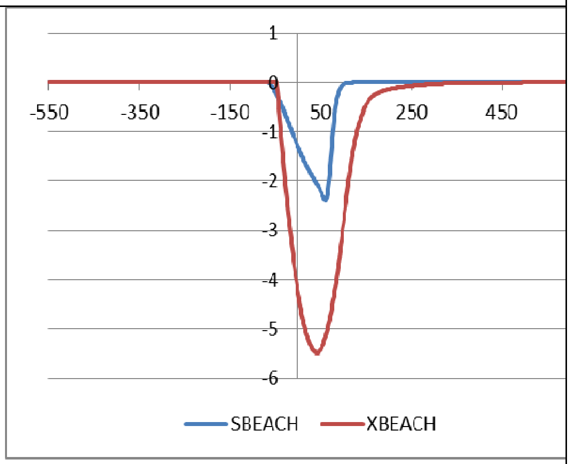
Run 2.3



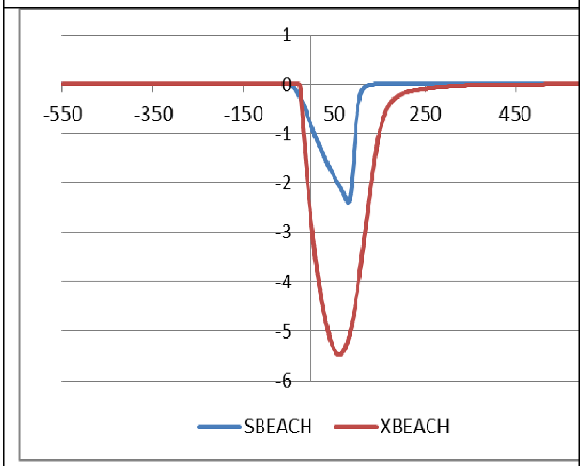
Run 2.4



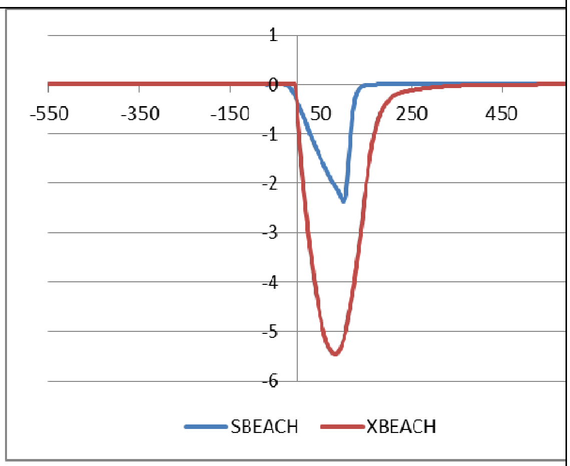
Run 2.5



Run 2.6



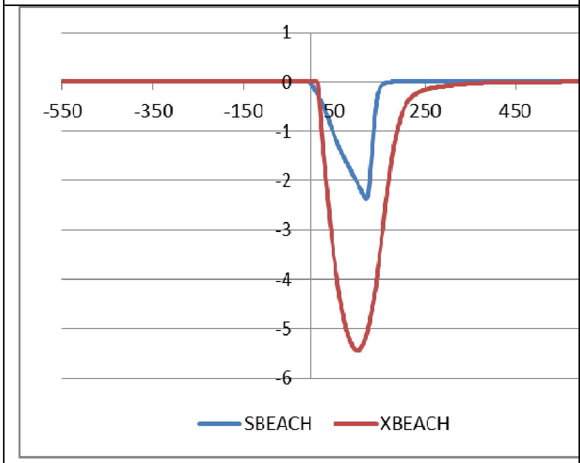
Run 2.7



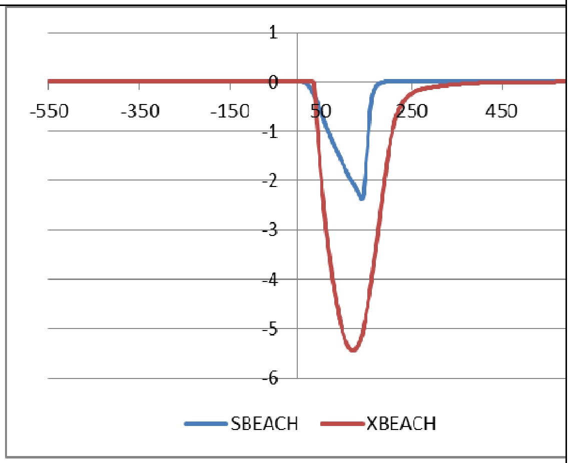
Distance from Mean Sea Level (m)

Sediment Transport Rate (m^3/m/h)

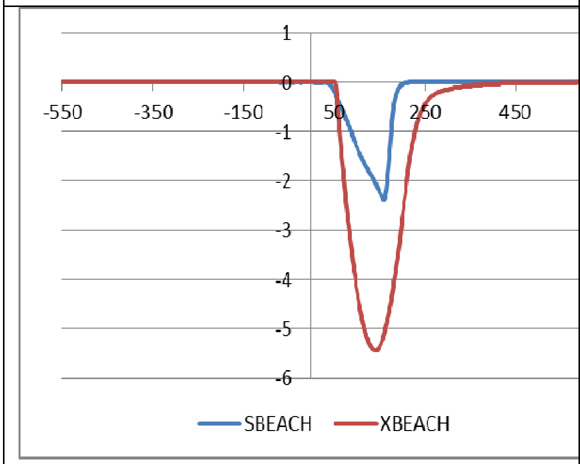
Run 2.8



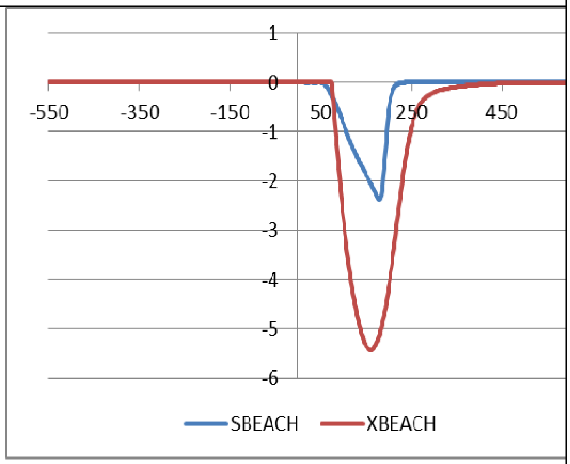
Run 2.9



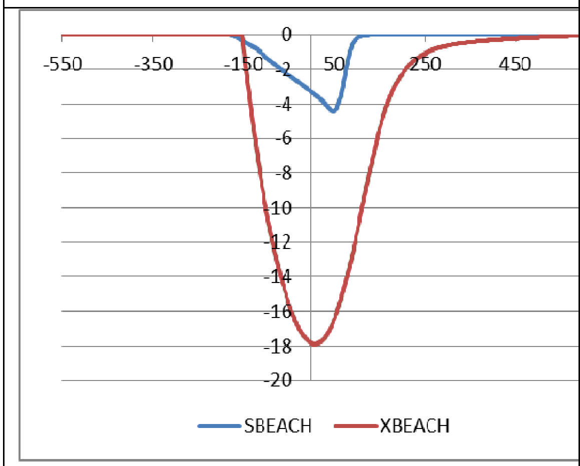
Run 2.10



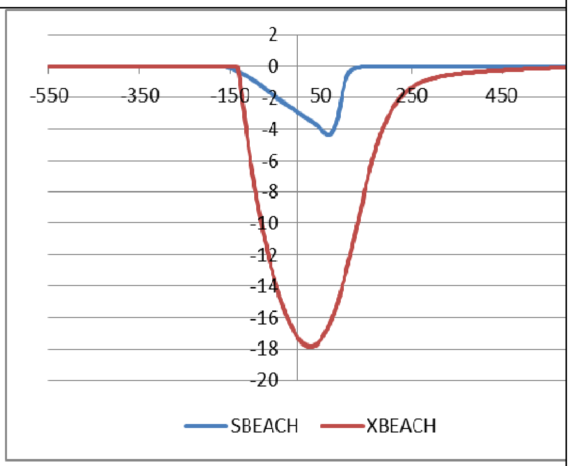
Run 2.11



Run 3.1



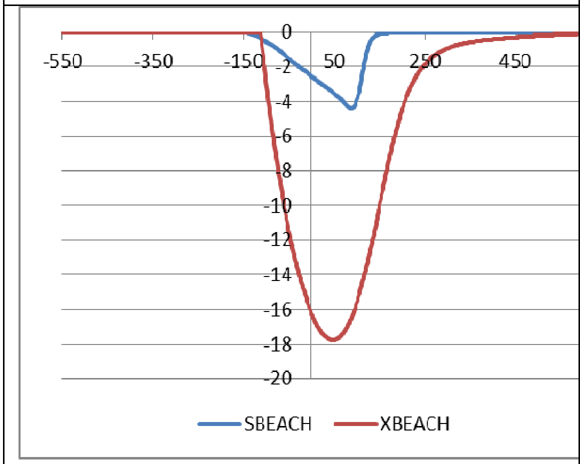
Run 3.2



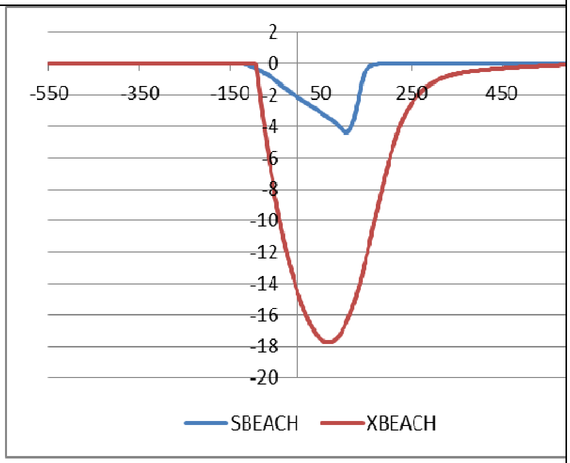
Sediment Transport Rate (m^3/m/h)

Distance from Mean Sea Level (m)

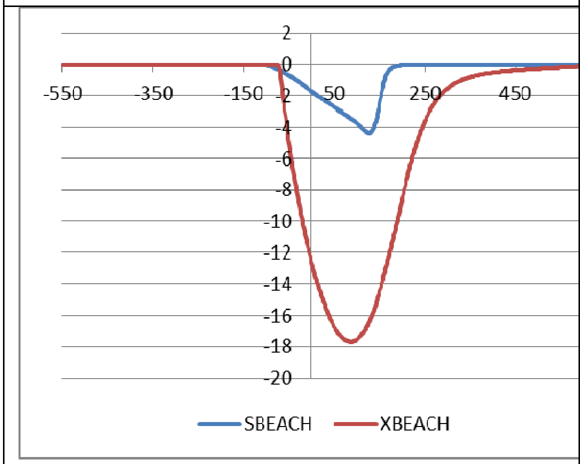
Run 3.3



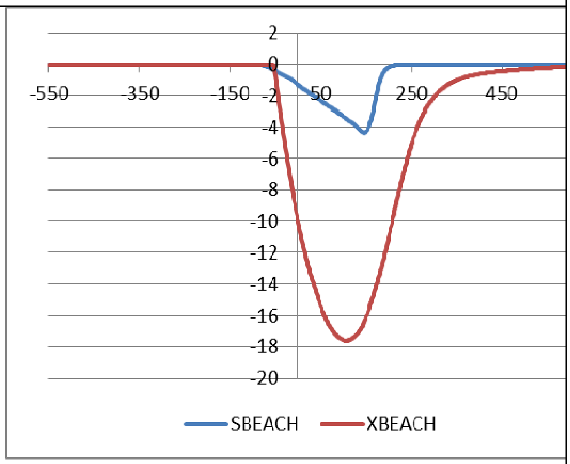
Run 3.4



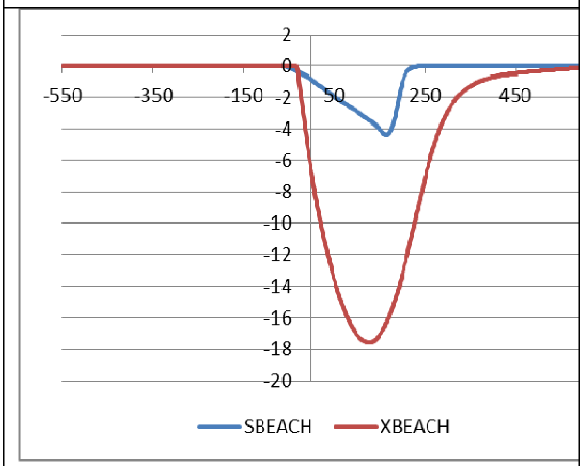
Run 3.5



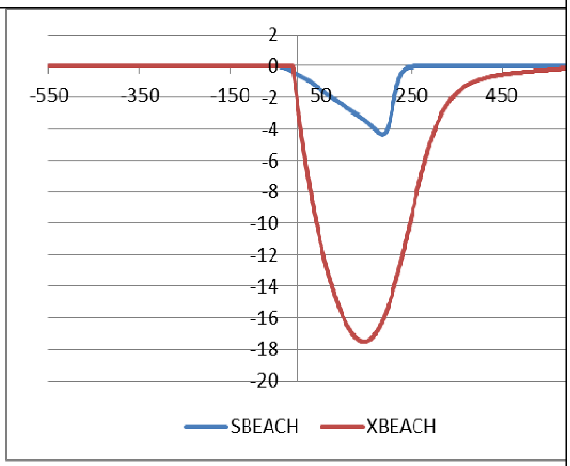
Run 3.6



Run 3.7



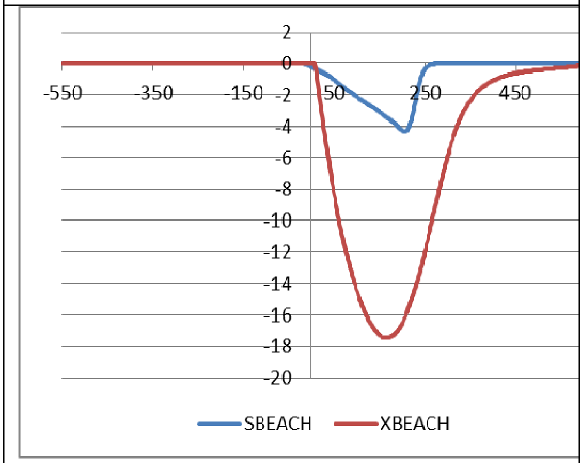
Run 3.8



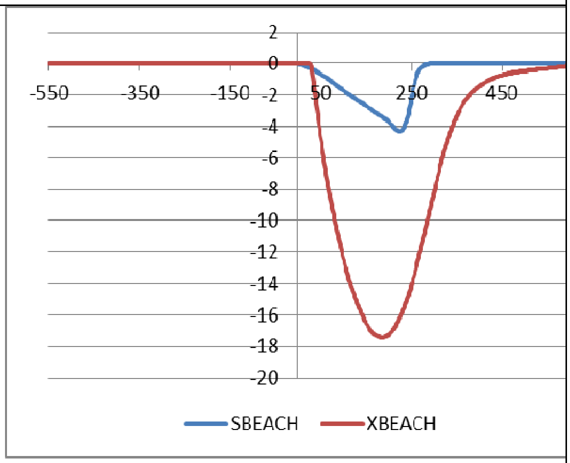
Sediment Transport Rate (m³/m/h)

Distance from Mean Sea Level (m)

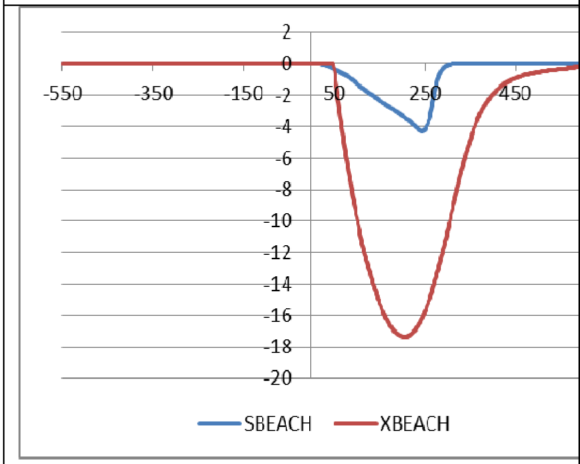
Run 3.9



Run 3.10



Run 3.11



APPENDIX B: STORM DURATION SENSITIVITY

Appendix B-1: Model Runs to Evaluate Sensitivity to Storm Duration

Run	Wave Height (m)	Wave Period (s)	Water Elevation Above MSL (m)	Duration (h)
2.1	3	12	+2	12
2.2	3	12	+2	18
2.3	3	12	+2	24
2.4	3	12	+2	30
2.5	3	12	+2	36
2.6	3	12	+2	42
2.7	3	12	+2	48
2.8	3	12	+2	54
2.9	3	12	+2	60
2.10	3	12	+2	66
2.11	3	12	+2	72
2.12	3	12	+2	78
2.13	3	12	+2	84
2.14	3	12	+2	90
2.15	3	12	+2	96
3.1	7	16	+4	12
3.2	7	16	+4	18
3.3	7	16	+4	24
3.4	7	16	+4	30
3.5	7	16	+4	36
3.6	7	16	+4	42
3.7	7	16	+4	48
3.8	7	16	+4	54
3.9	7	16	+4	60
3.10	7	16	+4	66
3.11	7	16	+4	72
3.12	7	16	+4	78
3.13	7	16	+4	84
3.14	7	16	+4	90
3.15	7	16	+4	96

Appendix B-2: Model Configuration/Parameter Setups for Storm Duration Sensitivity

****

* SBEACH model configuration file: SD2(1-8).CFG *

****

A--------------------------- MODEL SETUP ------------------------------A

A.1 RUN TITLE: TITLE

SD2: +2m MSL Water Elevation, Wave condition 1-8

A.2 INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS

1

A.3 TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY

RELATIVE TO INITIAL PROFILE: NDX, XSTART

766 -550.0

A.4 GRID TYPE (CONSTANT=0, VARIABLE=1): IDX

0

A.5 COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6 CONSTANT GRID CELL WIDTH: DXC

1.5

A.7 COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8 NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID

4

A.9 GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD

TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)

(10, 2) (1, 38) (1, 800) (10, 50)

A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT

5760 1.0

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR

8

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)

720 1080 1440 1800 2160 2520 2880 3240

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP

0

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH

WILL BE DETERMINED): ELV1, ELV2, ELV3

10.00 3.00 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM

POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF

LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED

EDP1, EDP2, EDP3, REFELV

10.00 5.00 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K

1.75E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS

0.002000

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM

0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC

20.00

B---------------------- WAVES/WATER ELEVATION/WIND -----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE

1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE

0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T

3.00 12.00

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV

60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG

0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN

0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG

0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS

0.00

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND

0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC

7878 20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV

0

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV

2.00

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV

60.00

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND

0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND

0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND

0.00

C------------------------------ BEACH ----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN

1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,

LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,

END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,

XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS

0.30

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50

0.25

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX

20.00

D------------------------------ BEACH FILL ---------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL

0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE

TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START

AND END OF BEACH FILL: NFILL

0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE

INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E-------------------------- SEAWALL/REVETMENT ---------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL

0

E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.

E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL

0.00

E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL

0

E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.

E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION

AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES

FAILURE: PEFAIL, WEFAIL,HFAIL

0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F

----------------------------------- END ------------------------------------

```
%%% XBeach parameter settings input file %%%

%%% date: 03-Aug-2016 12:00 %%%

%%% function: xb_write_params %%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

gridform = xbeach

depfile = DepSeaLevel.dep

posdwn = -1

alfa = 0

dx = 1.5

dy = 0

nx = 765

ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90

thetamax = +90

dtheta = 10

thetanaut = 0

 %%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tstart = 0

tstop = 345600

tintg = 60

tintp = 60

 %%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 rho = 1025

g = 9.81

D50 = 0.00025

rhos = 2650
```

por = 0.3

%%% Flow boundary conditions %%%

front = abs_1d

back = abs_1d

left = 0

right = 0

%%% Tide boundary conditions %%

tideloc = 0

zs0 = 2

%%% Wave boundary Conditions %%

instat = 0

Hrms = 3

Trep = 12

lwave = 0

%%% Morphology Conditions %%

morfac = 1

morstart = 0

%%% Output variables %%%

outputformat = netcdf

nglobalvar = 6

zb
zb0
zs
H
hh
Qb

nmeanvar = 3

H
hh
zs

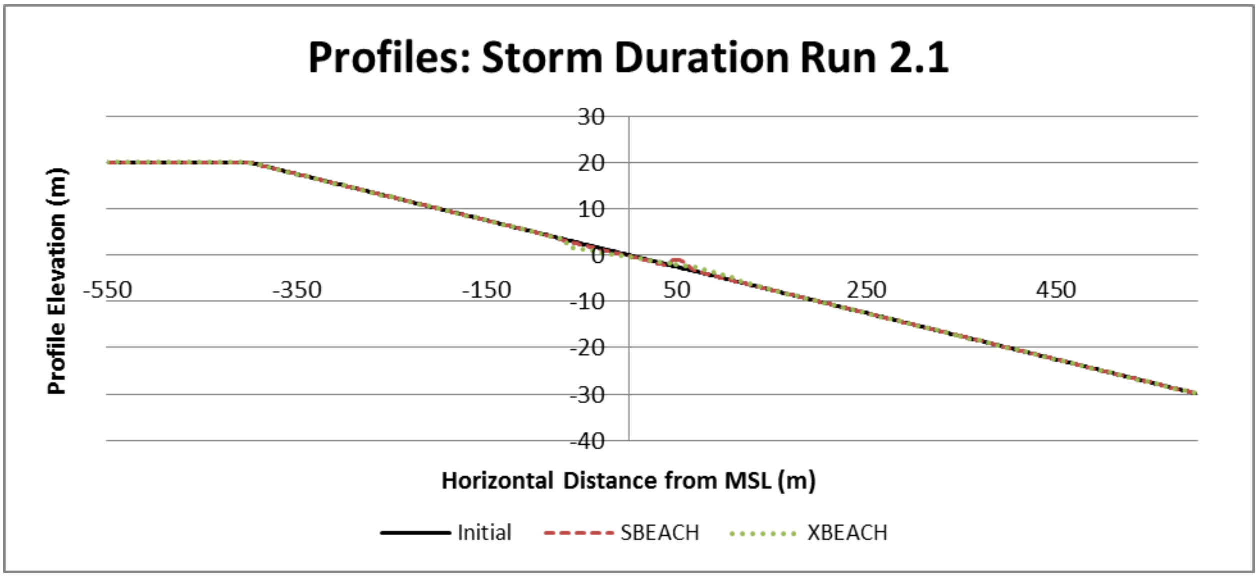
DUNERULE

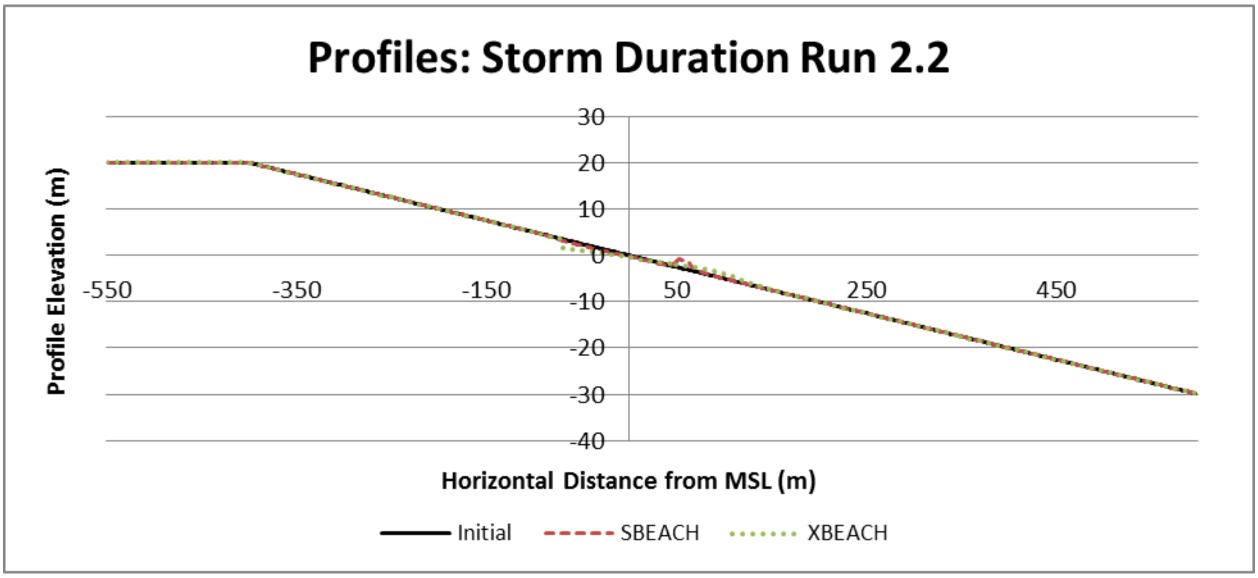
Input values in RED; computed values blue

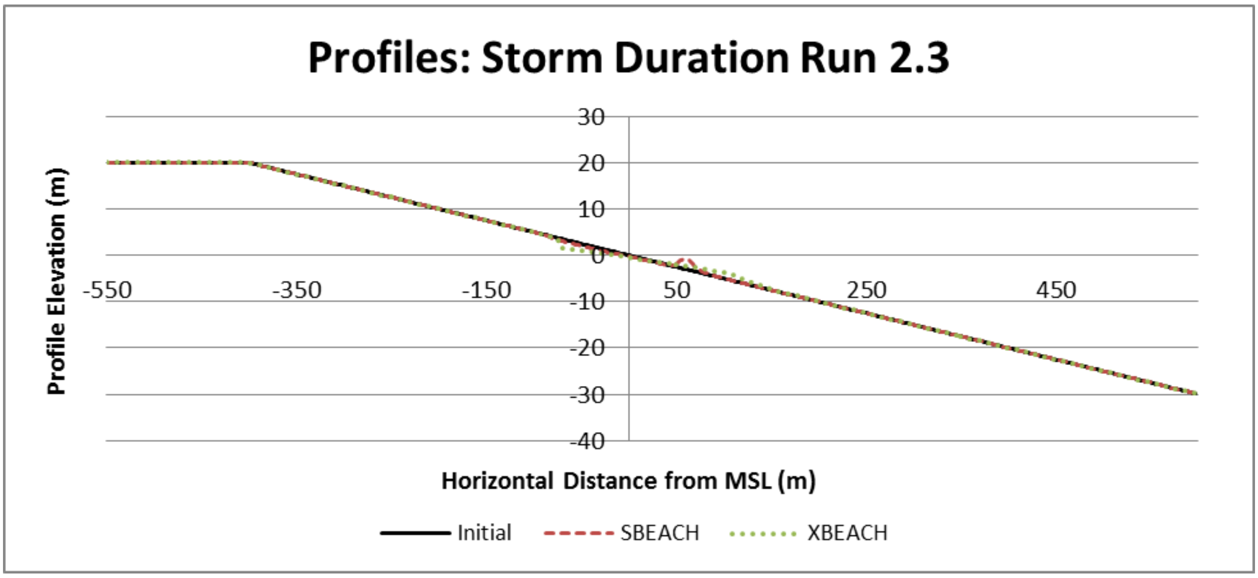
Case	Sediment Size d50 (m)	Surf Zone Slope tanb (-)	Offshore Wave Height Hs,o (m)	Wave Period Tp (s)	Wave Angle to Normal θ (deg)	Storm Surge Level (including wave setup and tide) SSL (m)	Dune height above MSL B (m)	Time t (h)
2.1	0.000250	0.0500	0.8	6.0	0	2	20	12

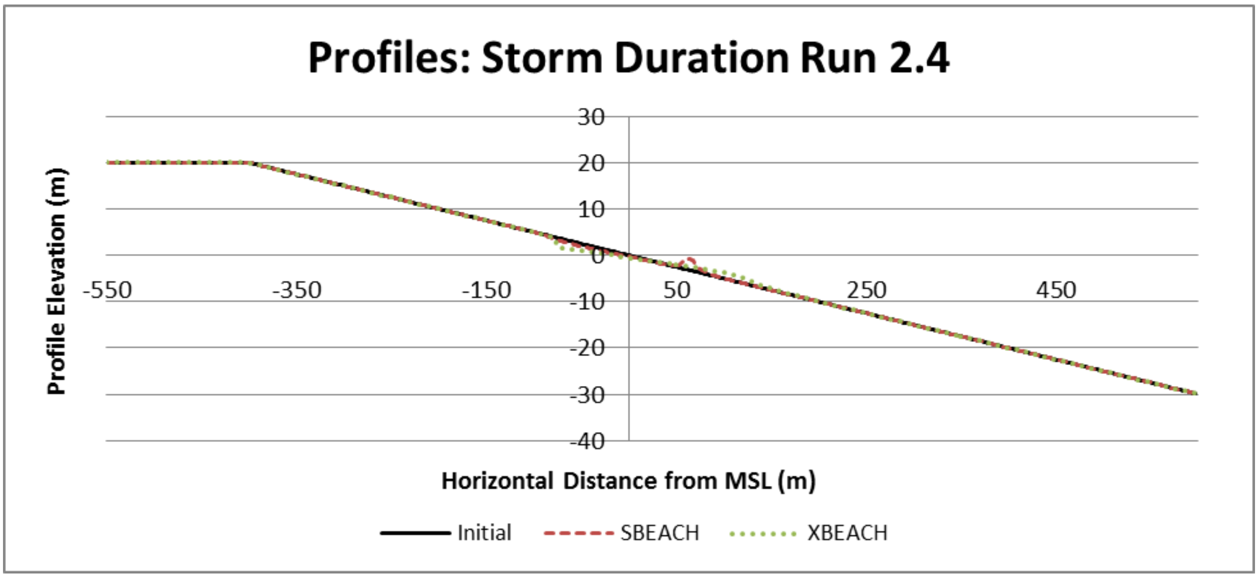
Dune Recession Van Rijn					
Erosion Volume After 5h (m3/m)	Mean Recession After 5h (m)	Maximum Recession After 5h (m)	Erosion Volume After t hours (m3/m)	Mean Recession After t hours (m)	Maximum Recession After t hours (m)
36.1061	2.0058969	3.00884535	43.0153401	2.38974112	3.58461167

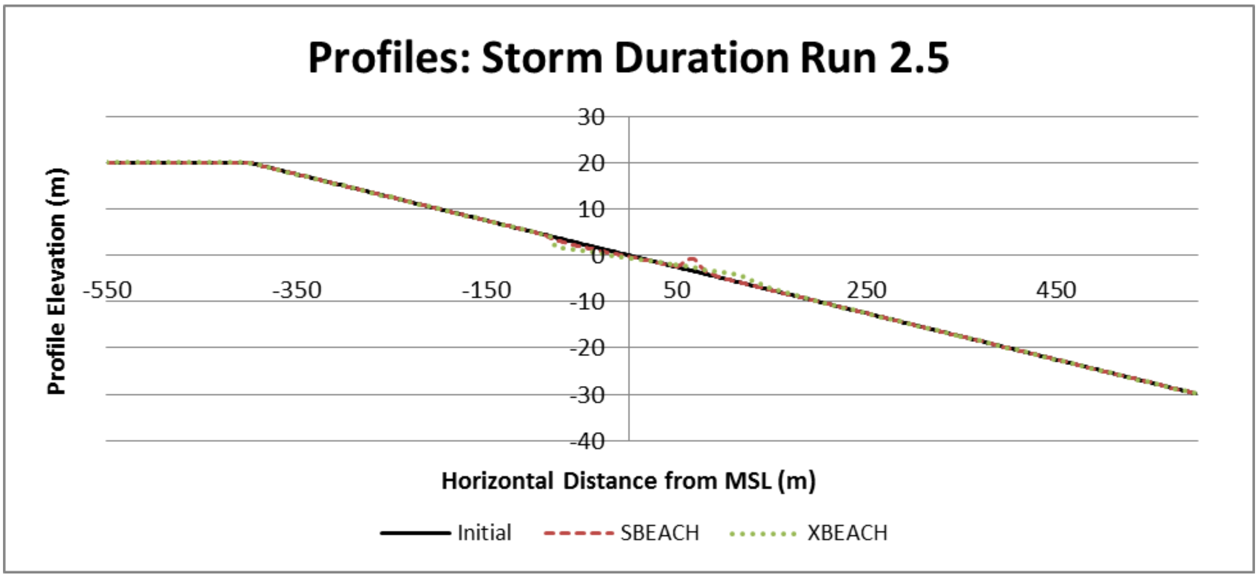
Appendix B-3: Storm Duration Model Sensitivity Runs Output

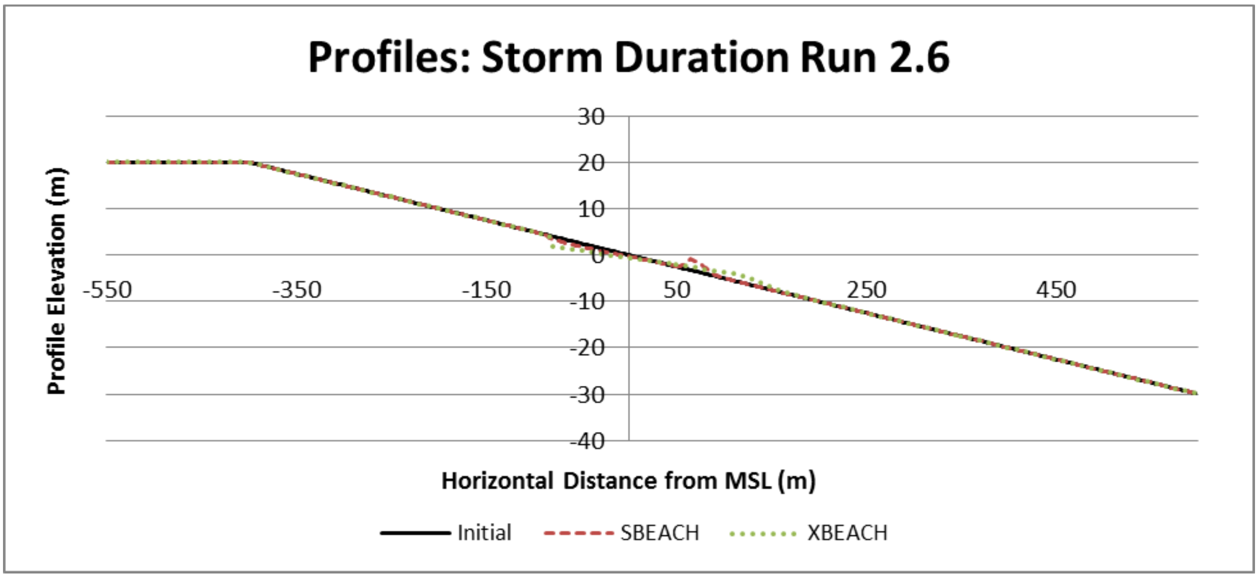


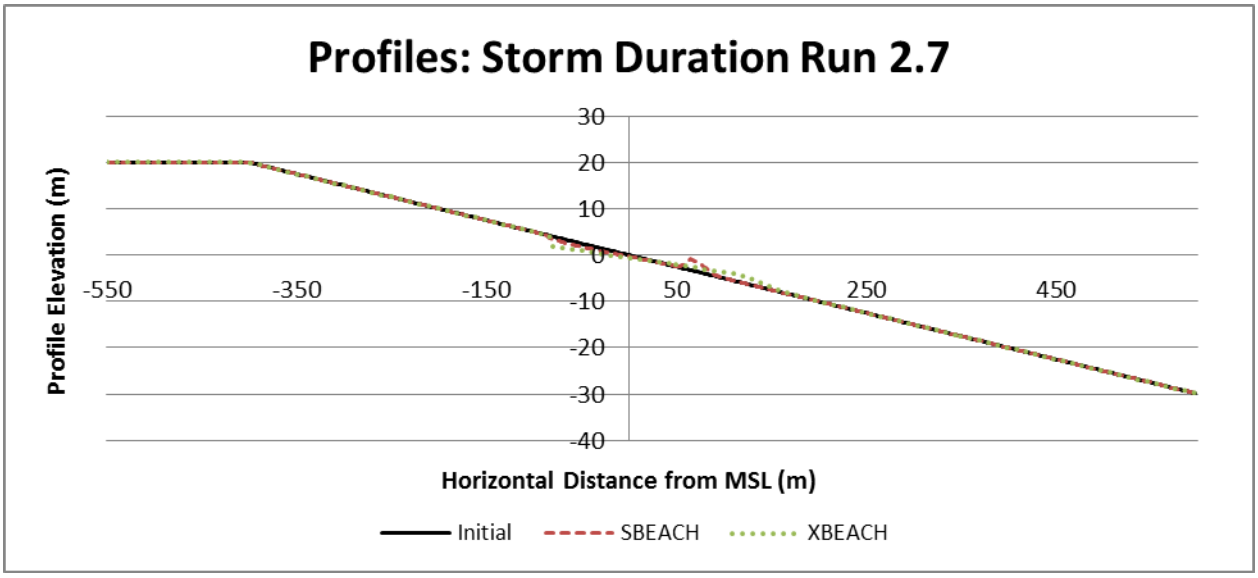


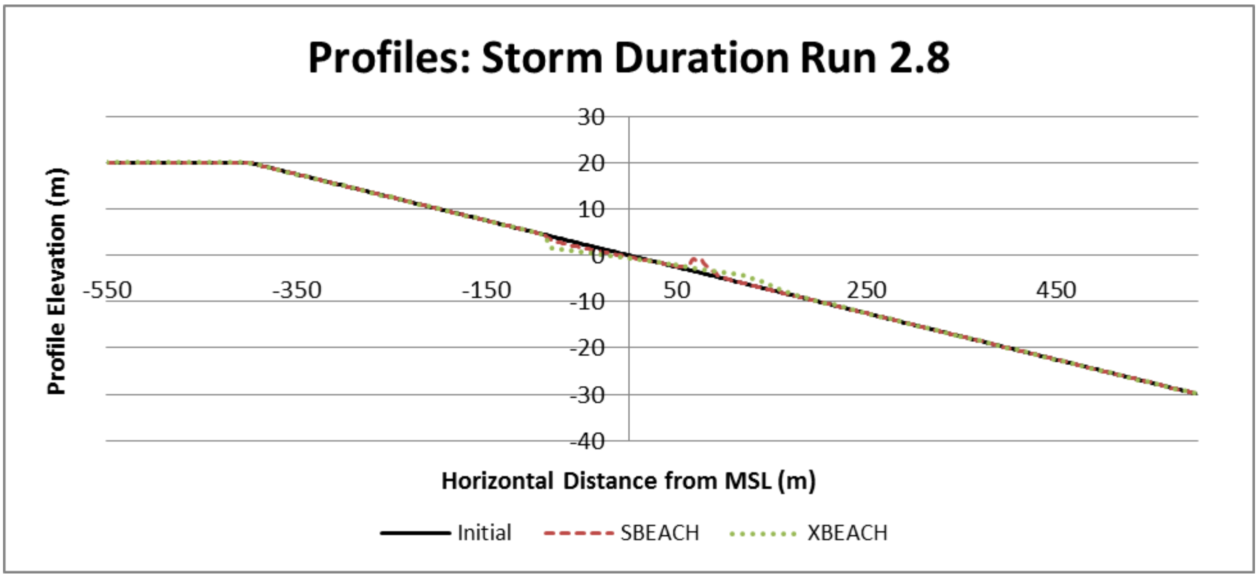


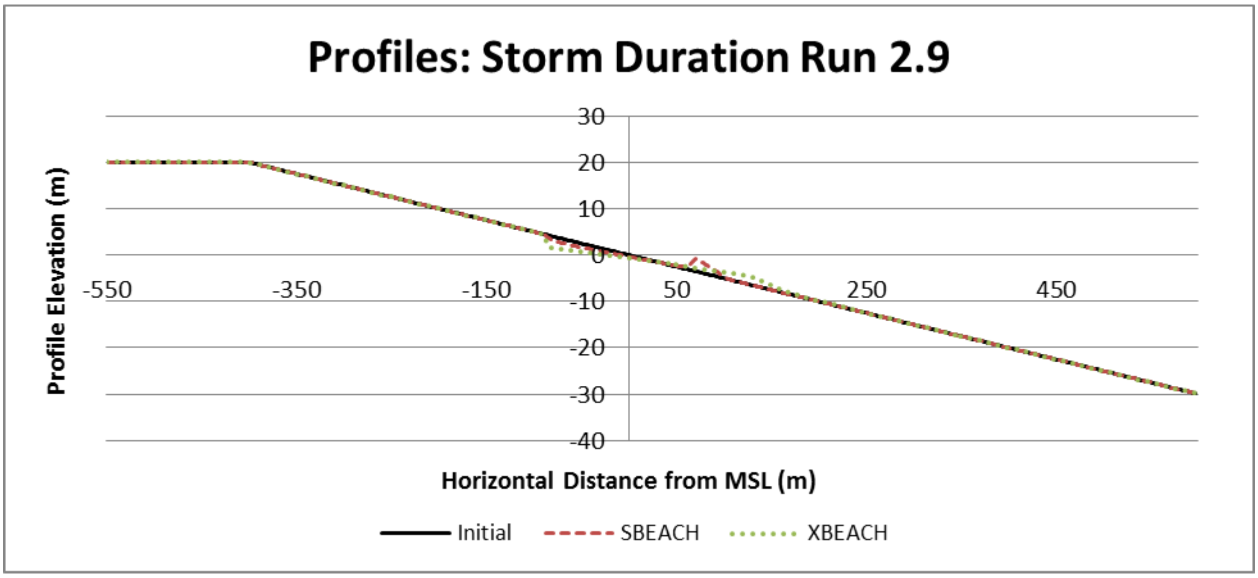

Profiles: Storm Duration Run 2.4
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

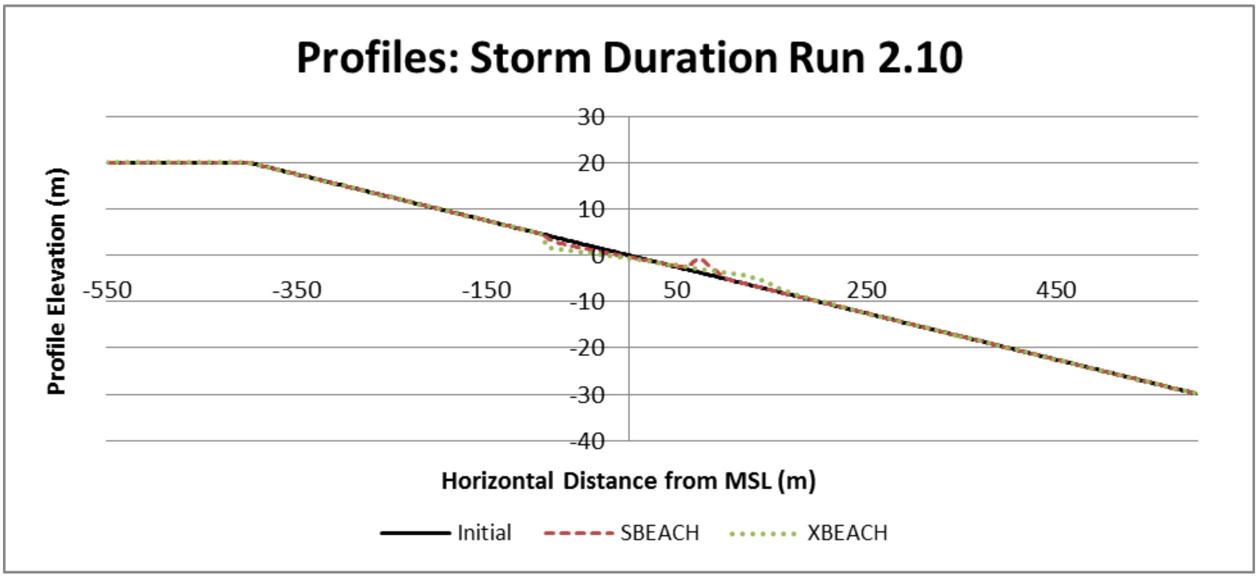

Profiles: Storm Duration Run 2.5
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

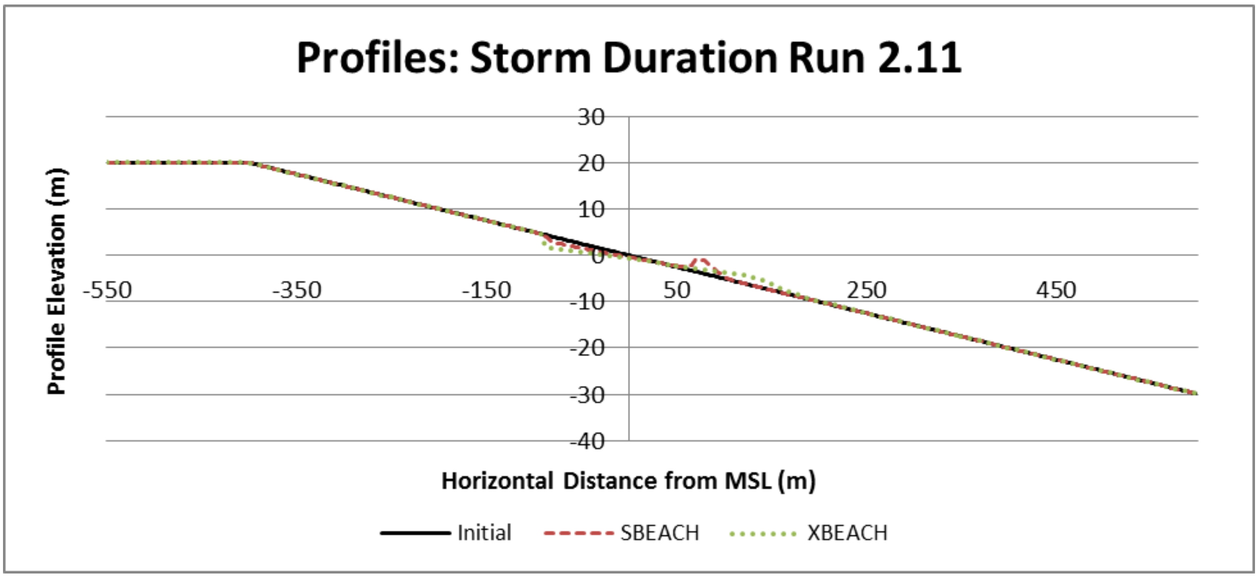

Profiles: Storm Duration Run 2.6
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

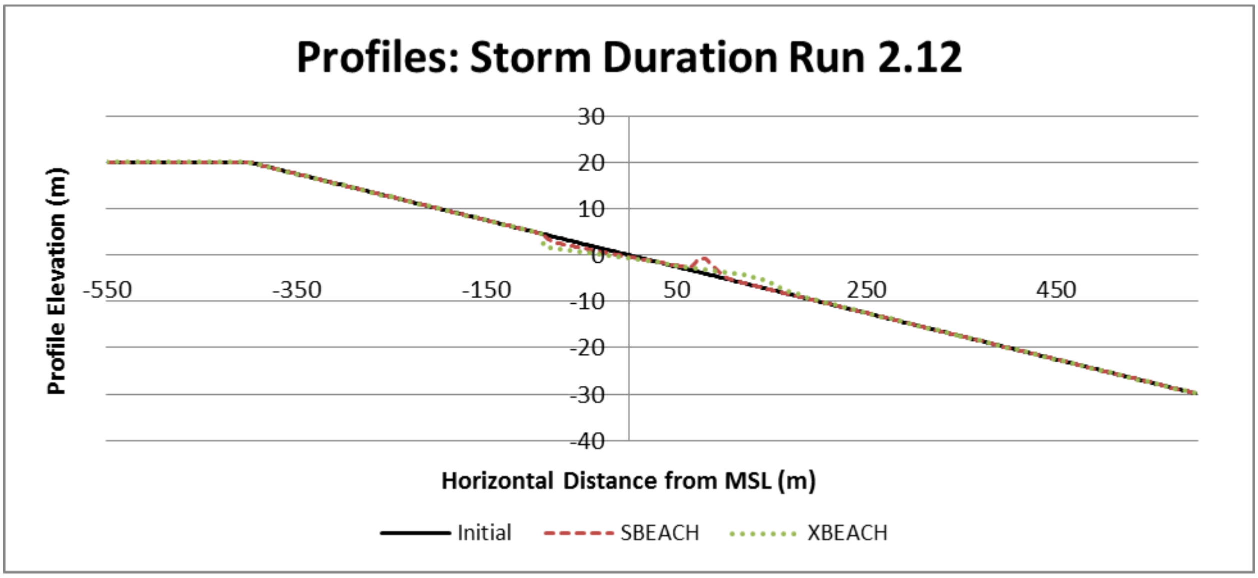

Profiles: Storm Duration Run 2.7
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

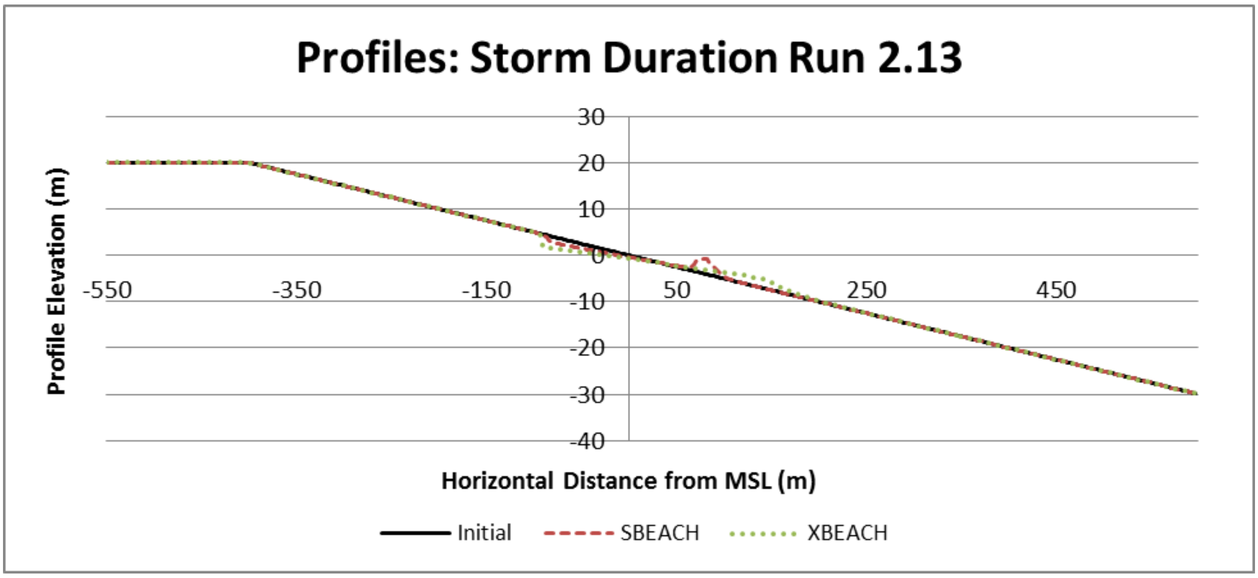

Profiles: Storm Duration Run 2.8
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

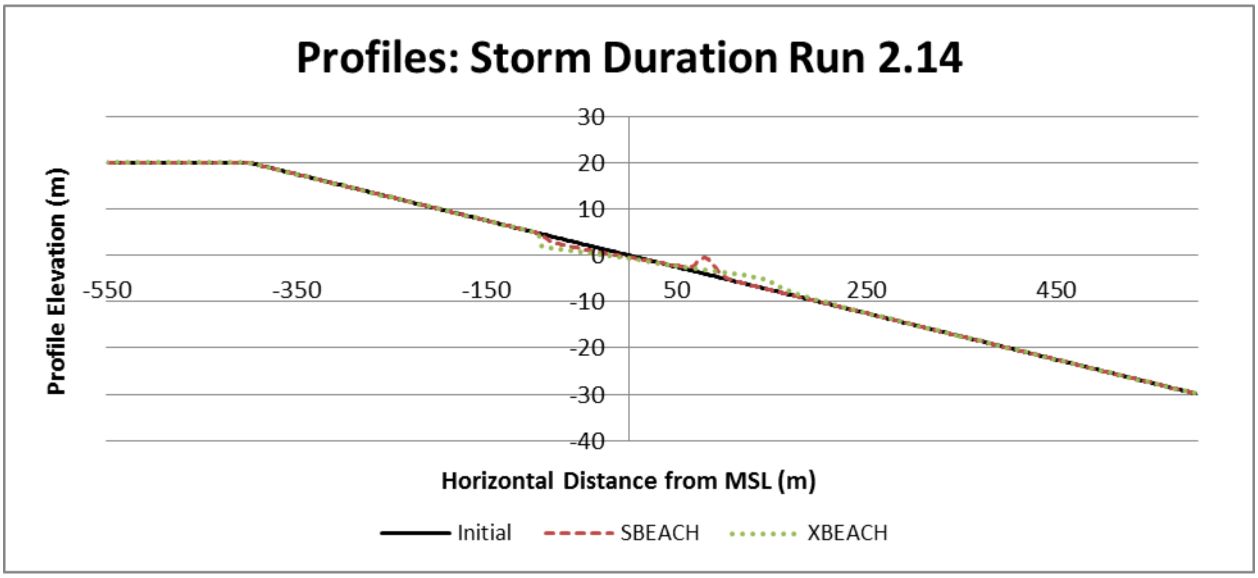

Profiles: Storm Duration Run 2.9
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

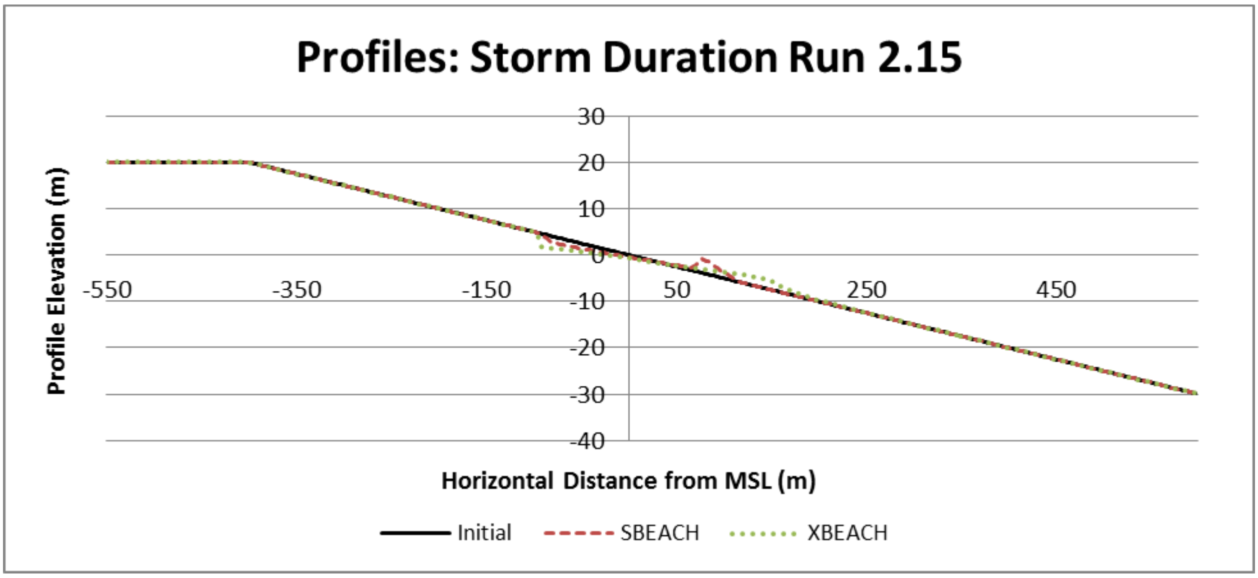

Profiles: Storm Duration Run 2.10
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

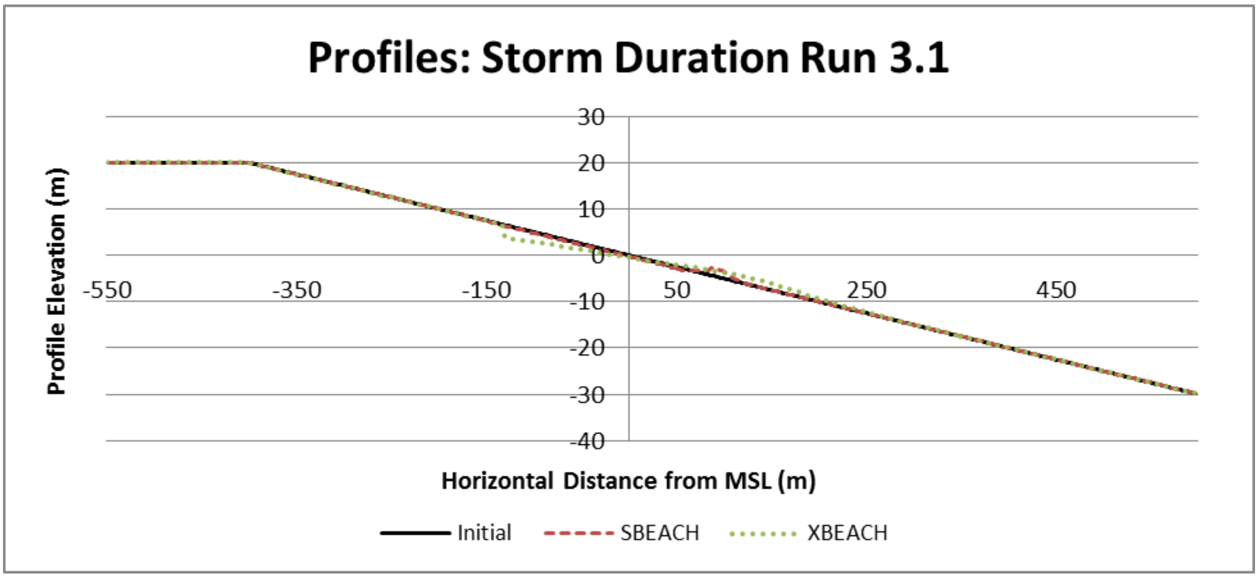

Profiles: Storm Duration Run 2.11
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

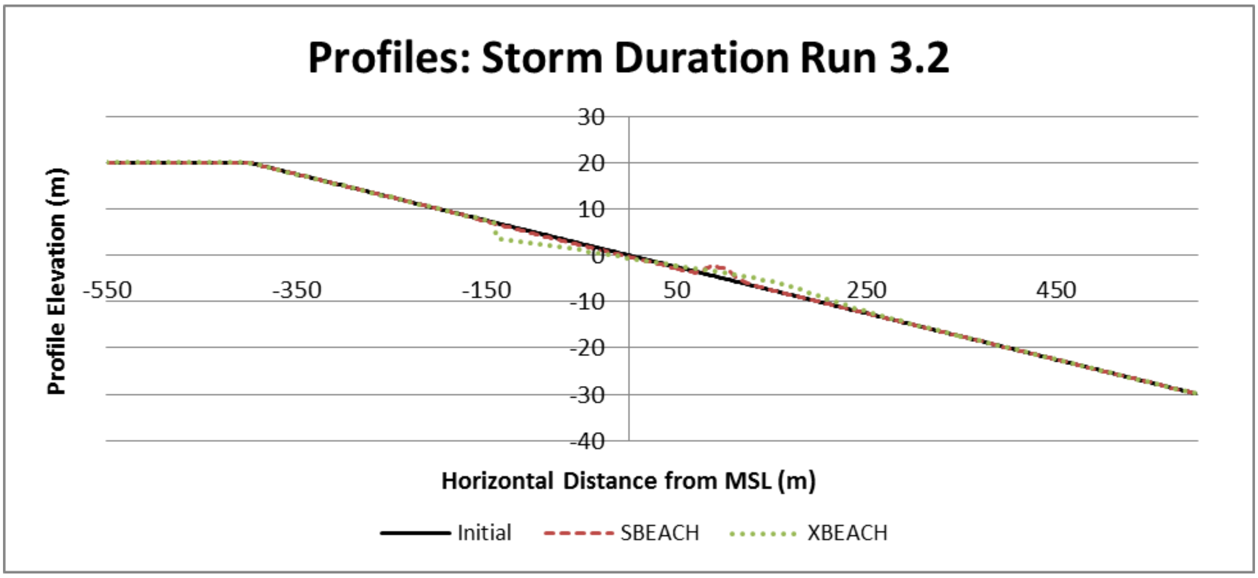

Profiles: Storm Duration Run 2.12
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

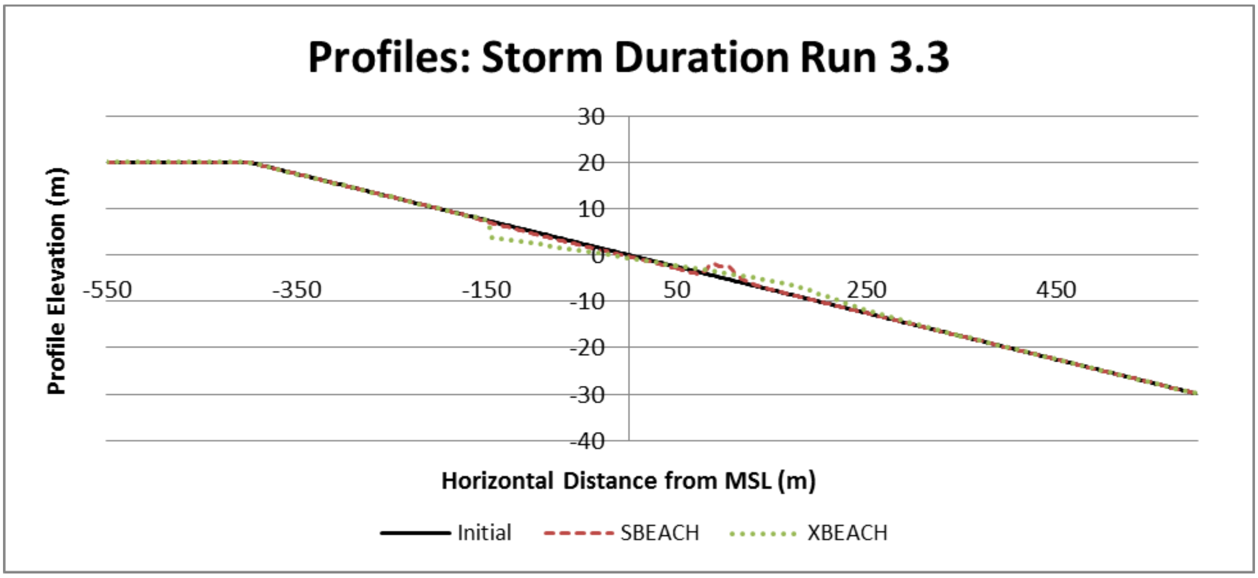

Profiles: Storm Duration Run 2.13
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

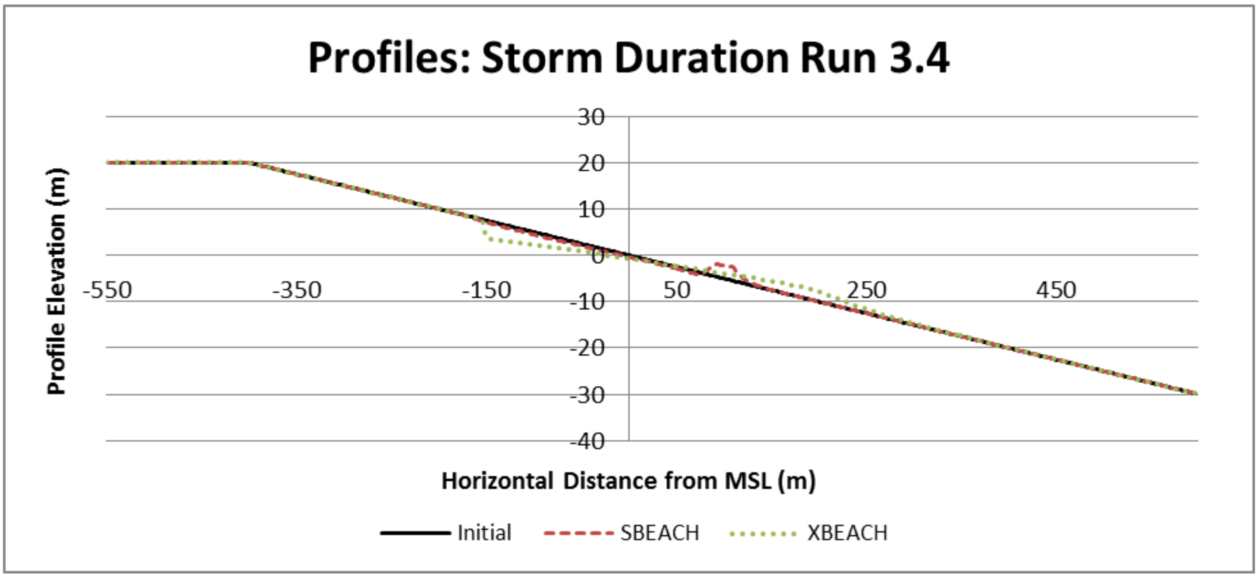

Profiles: Storm Duration Run 2.14
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

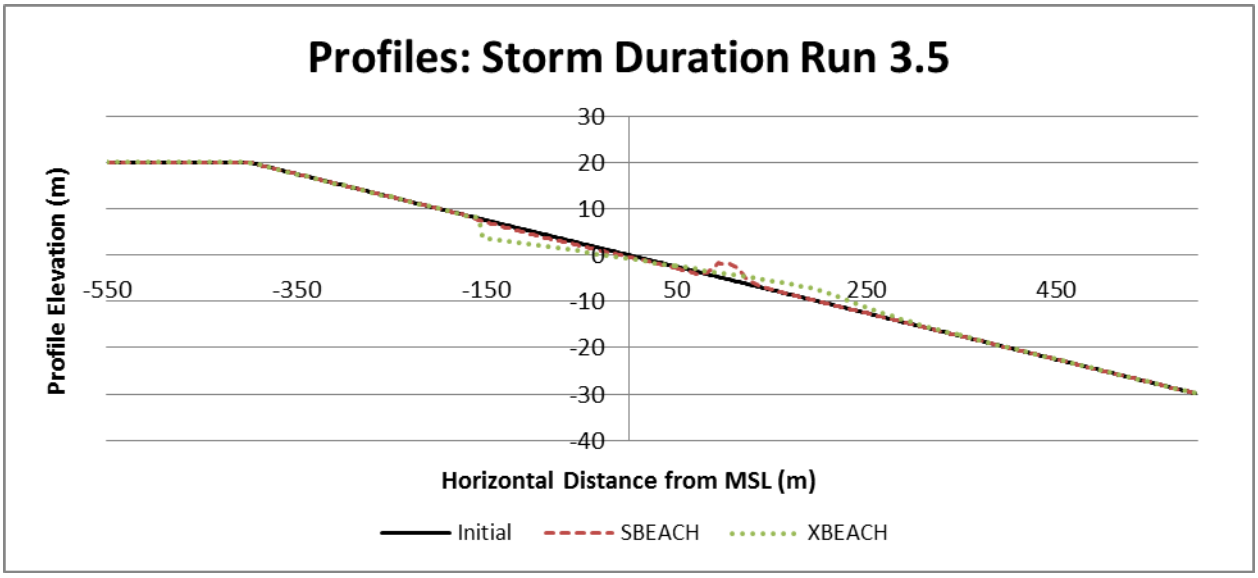

Profiles: Storm Duration Run 2.15
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

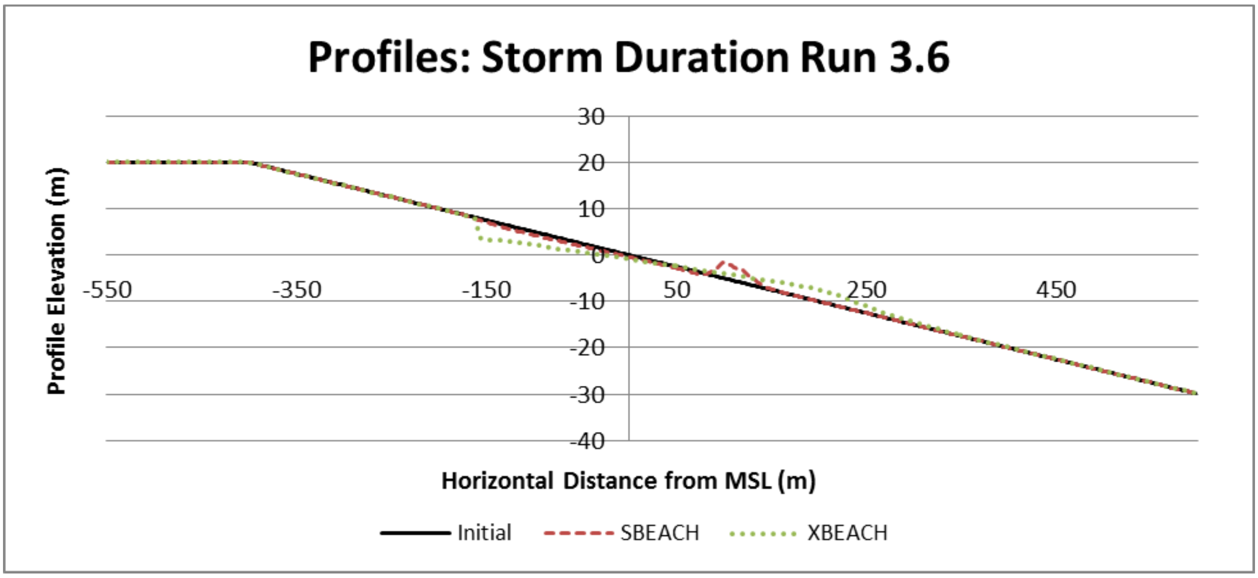

Profiles: Storm Duration Run 3.1
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

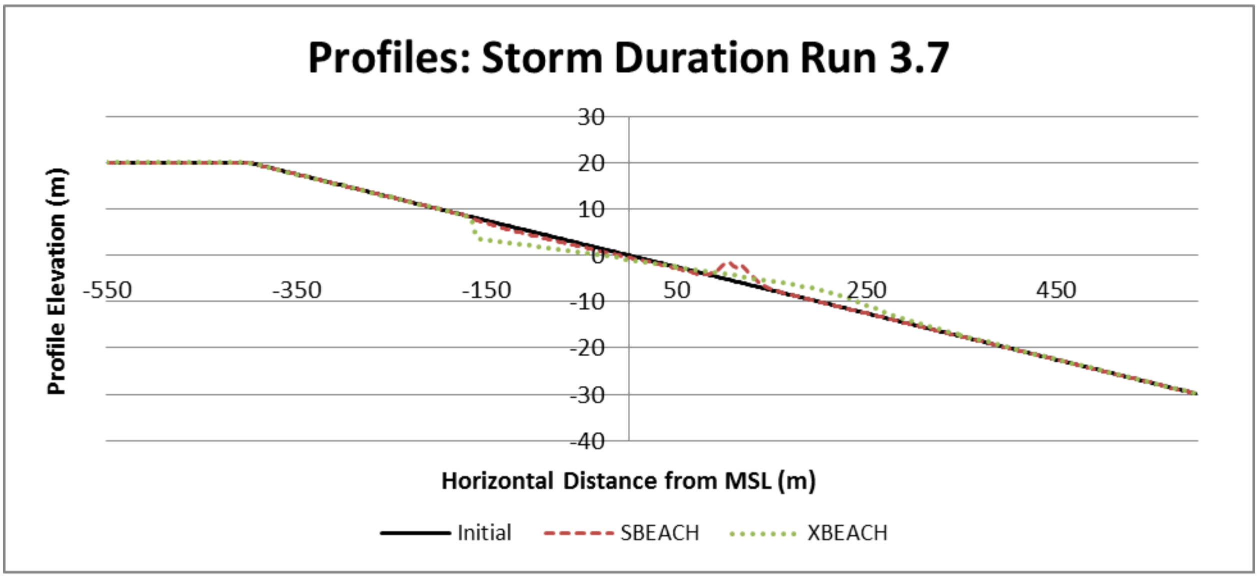

Profiles: Storm Duration Run 3.2
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

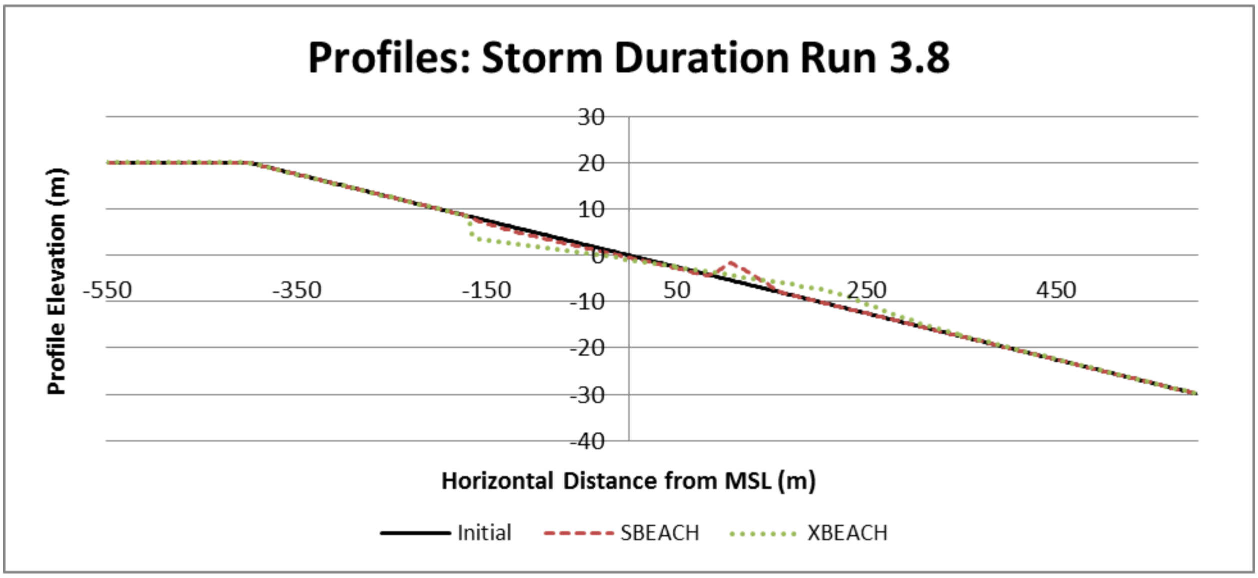

Profiles: Storm Duration Run 3.3
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

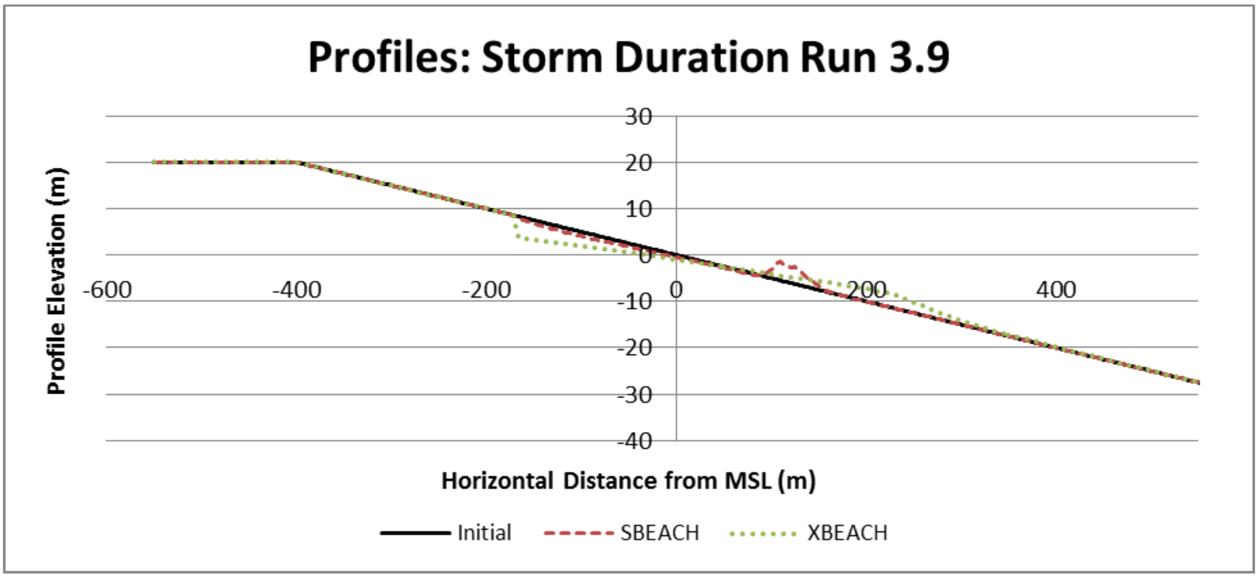

Profiles: Storm Duration Run 3.4
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

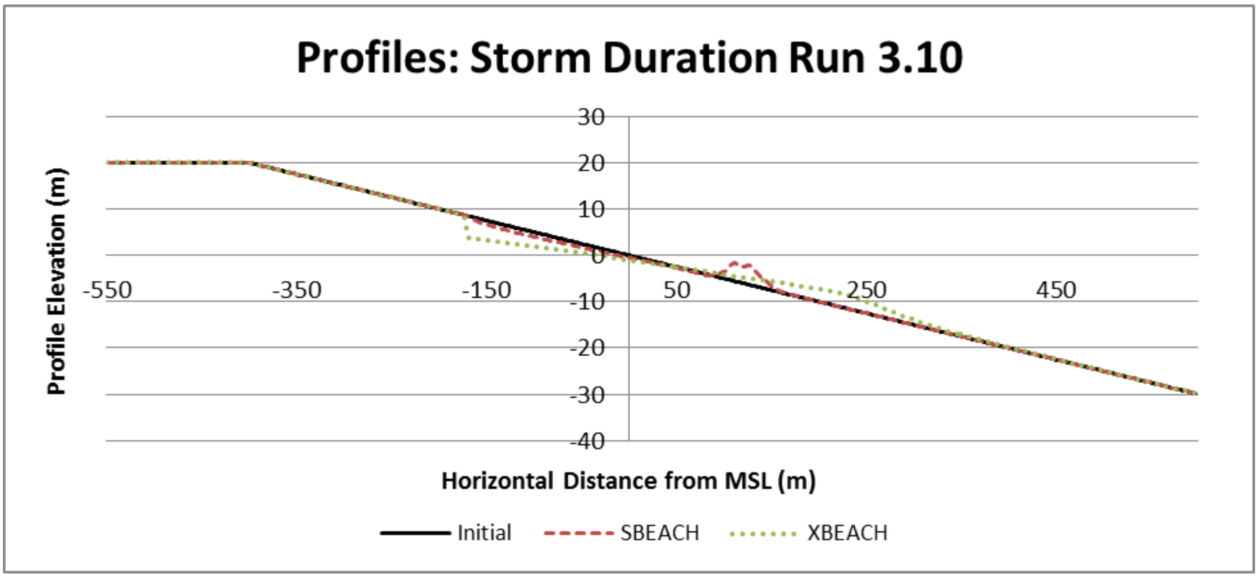

Profiles: Storm Duration Run 3.5
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

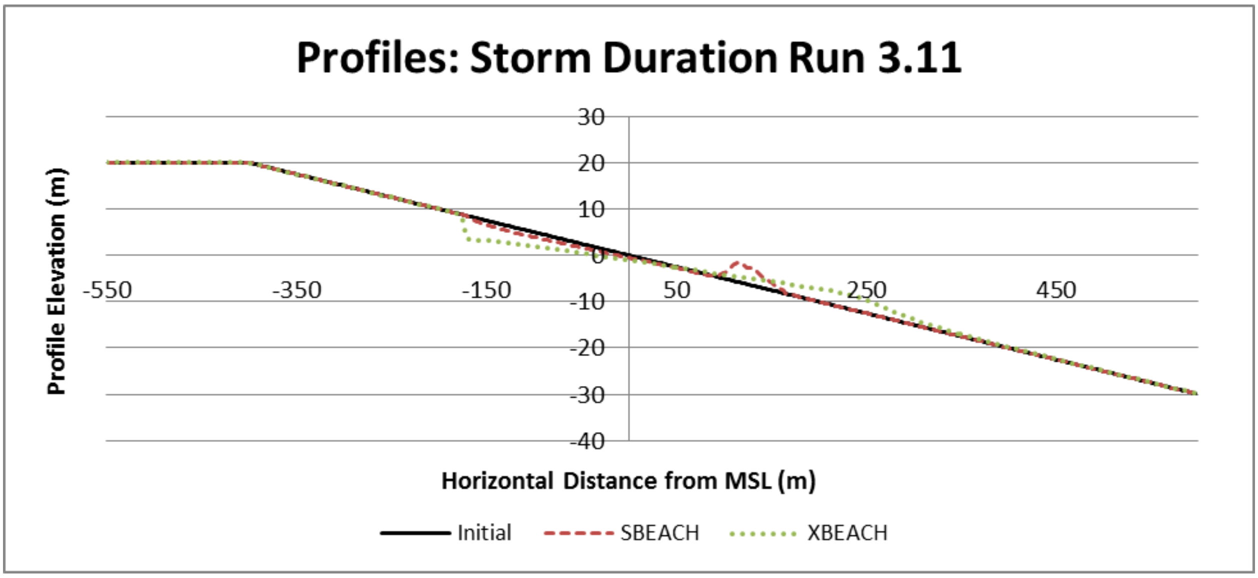

Profiles: Storm Duration Run 3.6
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

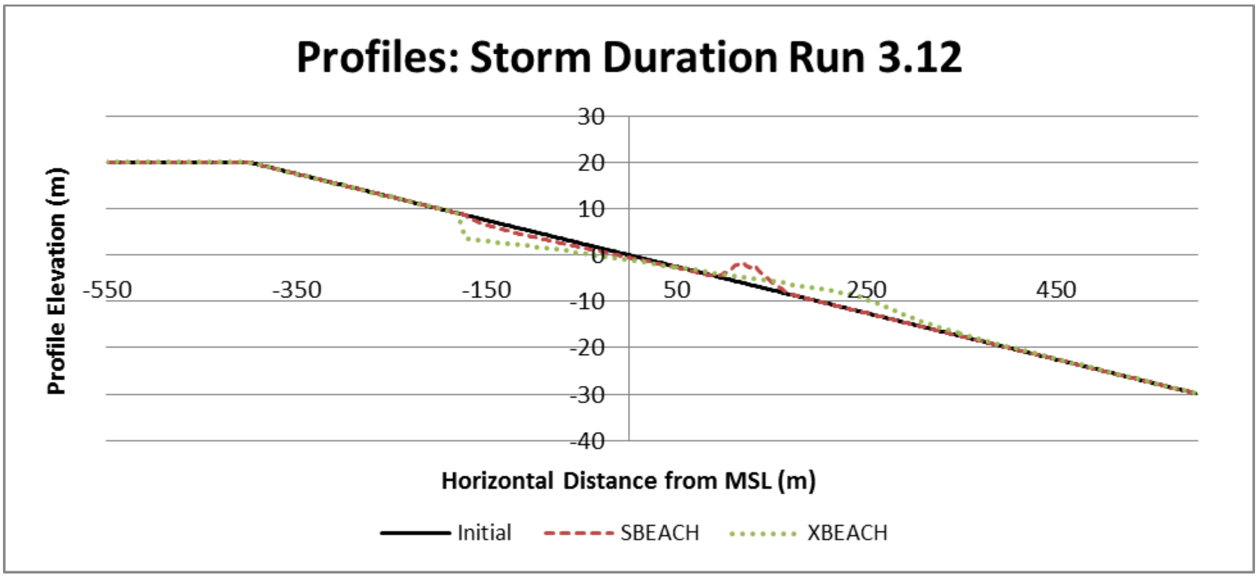

Profiles: Storm Duration Run 3.7
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

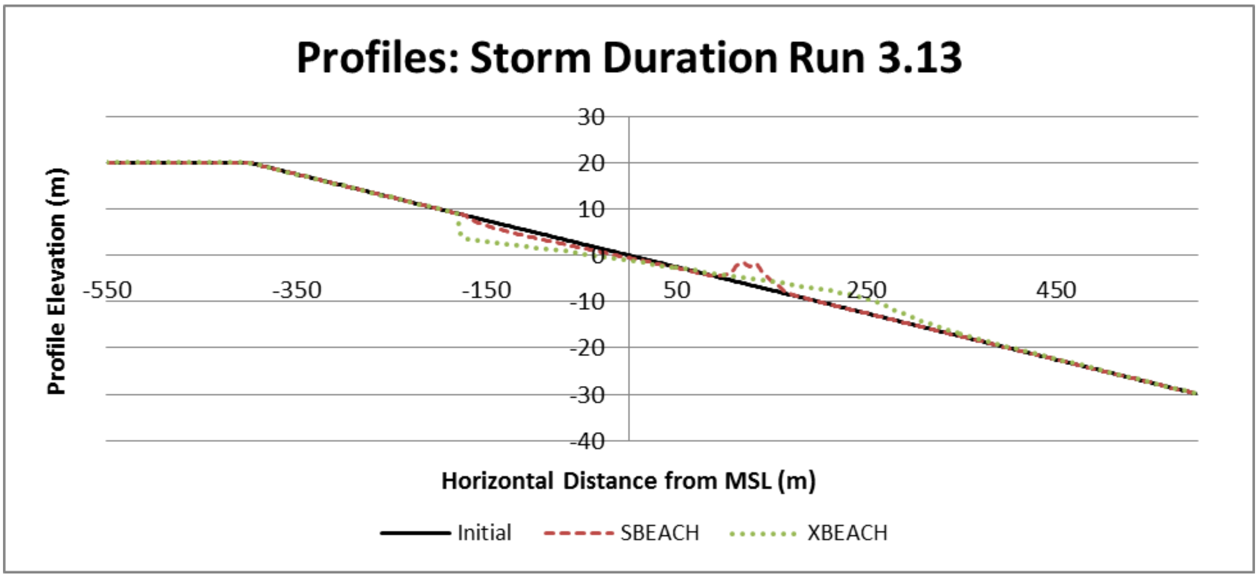

Profiles: Storm Duration Run 3.8
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Storm Duration Run 3.9
30
20
10
0
-10
-20
-30
-40
-600
-400
-200
0
200
400
Profile Elevation (m)
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

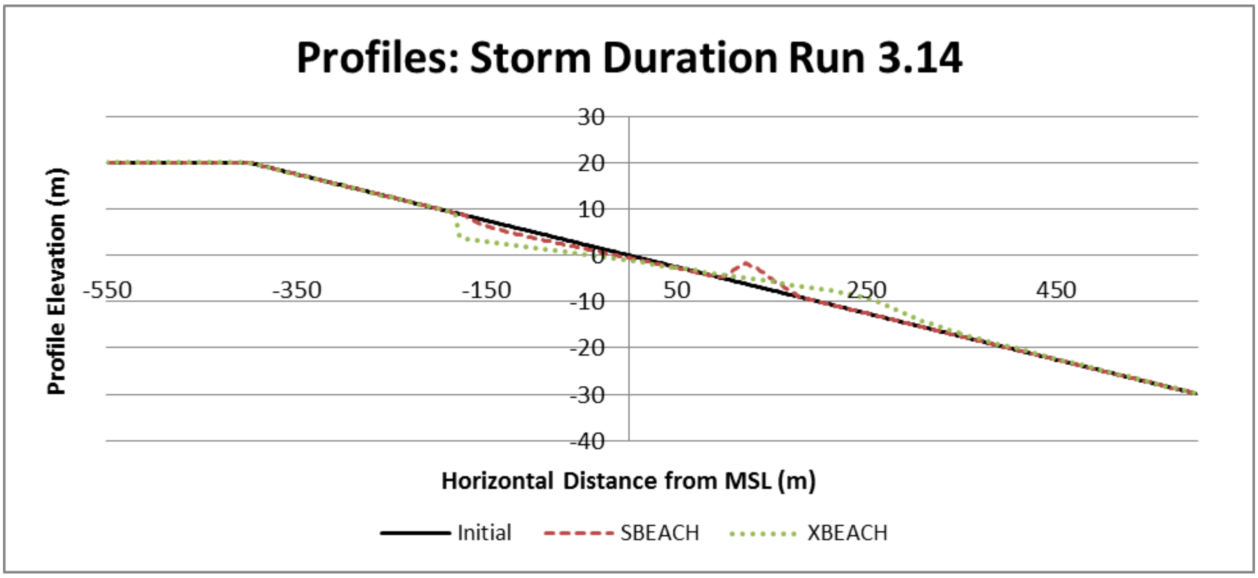

Profiles: Storm Duration Run 3.10
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Storm Duration Run 3.11
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH

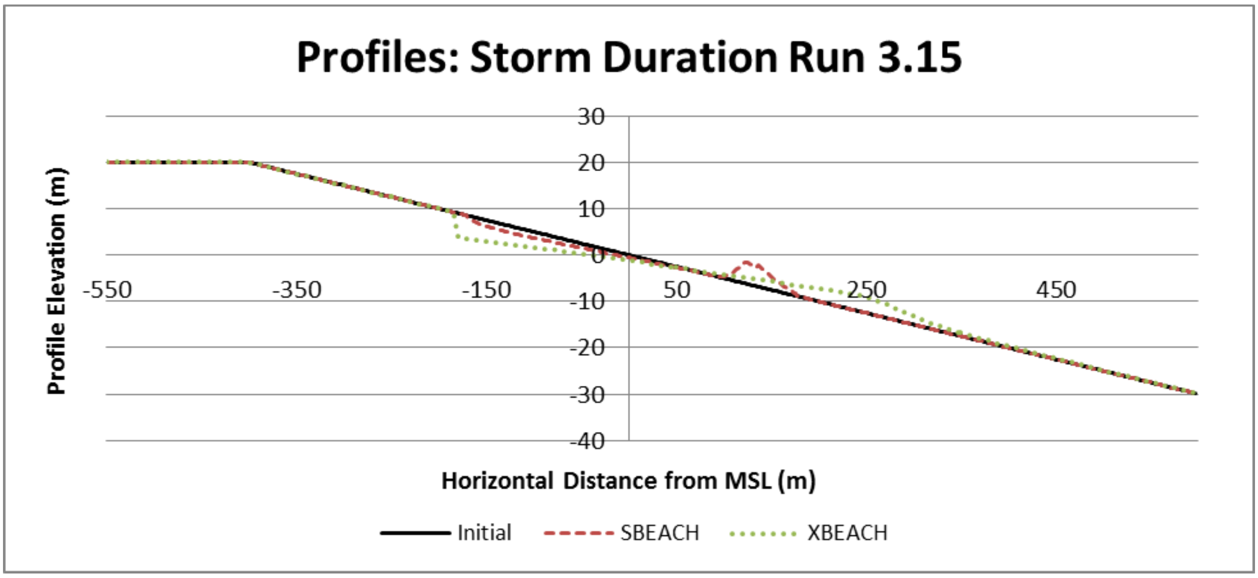

Profiles: Storm Duration Run 3.12
Profile Elevation (m)
Horizontal Distance from MSL (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH



Profiles: Storm Duration Run 3.13
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH



Profiles: Storm Duration Run 3.14
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH



Profiles: Storm Duration Run 3.15
Profile Elevation (m)
30
20
10
0
-10
-20
-30
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH

Appendix B-4: Storm Duration Sensitivity Comparison Parameters

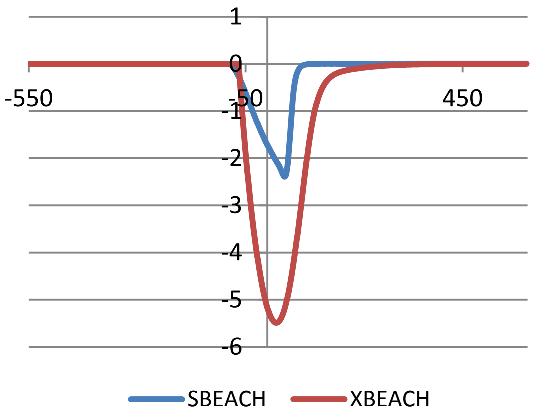
Run	Absolute Displaced Sediment Volumes (m^3/m)			Eroded Volume of Sediment Above Water Level (m^3/m)			Shoreline Recession (m)		
	SB	XB	DR	SB	XB	DR	SB	XB	DR
2.1	57.62	131.81	-	10.22	33.99	43.02	5.81	25.32	3.58
2.2	72.71	163.52	-	15.01	44.83	46.65	7.88	29.79	3.89
2.3	84.57	189.32	-	19.44	54.10	49.41	9.75	33.08	4.12
2.4	94.53	211.44	-	23.56	62.40	51.67	11.44	36.03	4.31
2.5	103.68	231.03	-	27.35	69.98	53.59	13.07	37.90	4.47
2.6	113.96	248.78	-	31.01	76.90	55.26	14.57	40.54	4.61
2.7	123.83	265.07	-	34.40	83.27	56.76	15.86	42.14	4.73
2.8	132.78	280.18	-	37.67	89.20	58.11	17.36	43.69	4.84
2.9	141.12	294.30	-	40.74	94.77	59.35	18.50	45.92	4.95
2.10	149.72	307.58	-	43.66	100.03	60.49	19.75	46.67	5.04
2.11	157.55	320.15	-	46.47	105.02	61.55	21.00	48.14	5.13
2.12	164.42	332.11	-	49.14	109.78	62.55	22.07	49.60	5.21
2.13	170.90	343.49	-	51.73	114.34	63.48	23.25	50.98	5.29
2.14	176.84	354.40	-	54.11	118.71	64.36	24.21	51.77	5.36
2.15	183.44	364.87	-	56.39	122.89	65.20	25.25	52.64	5.43
3.1	105.57	427.50	-	15.51	121.39	172.96	5.49	50.25	16.22
3.2	144.71	534.94	-	23.24	157.97	187.57	7.50	58.89	17.58
3.3	179.34	622.31	-	30.96	189.12	198.68	9.56	65.07	18.63
3.4	206.54	697.19	-	38.40	216.70	207.75	11.28	69.66	19.48
3.5	230.18	763.43	-	45.75	241.61	215.46	12.99	74.14	20.20
3.6	252.56	823.21	-	52.92	264.50	222.21	14.63	77.21	20.83
3.7	273.29	878.00	-	59.94	285.68	228.22	16.13	80.32	21.40
3.8	292.22	928.76	-	66.83	305.37	233.66	17.63	83.29	21.91
3.9	311.21	976.17	-	73.49	323.82	238.64	18.99	86.21	22.37
3.10	328.56	1020.76	-	80.05	341.23	243.23	20.44	89.15	22.80
3.11	345.80	1062.94	-	92.78	357.76	247.50	21.78	90.88	23.20
3.12	362.37	1103.01	-	98.94	373.55	251.50	23.06	93.65	23.58
3.13	377.25	1141.21	-	104.93	388.67	255.25	24.35	95.24	23.93
3.14	392.78	1177.77	-	110.87	403.18	258.80	25.63	97.45	24.26
3.15	408.42	1212.89	-	86.46	417.15	262.16	26.92	99.64	24.58

Appendix B-5: Storm Duration Sensitivity Sediment Transport Rate Distributions

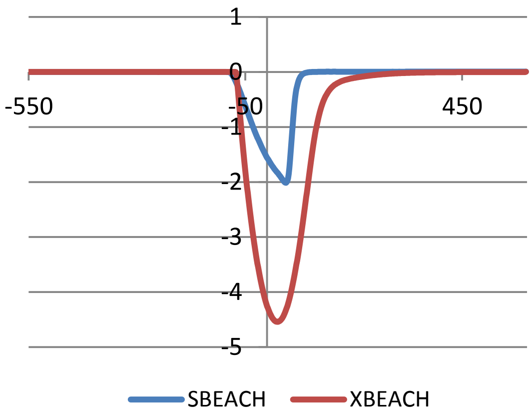
Sediment Transport Rate (m³/m/h)

Distance from Mean Sea Level (m)

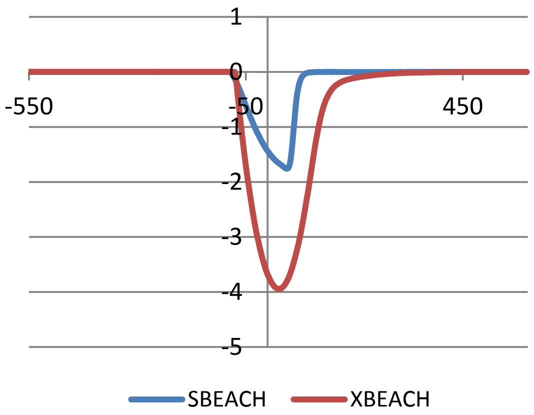
Run 2.1



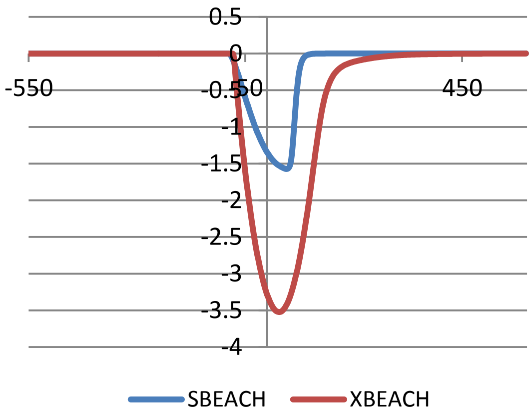
Run 2.2



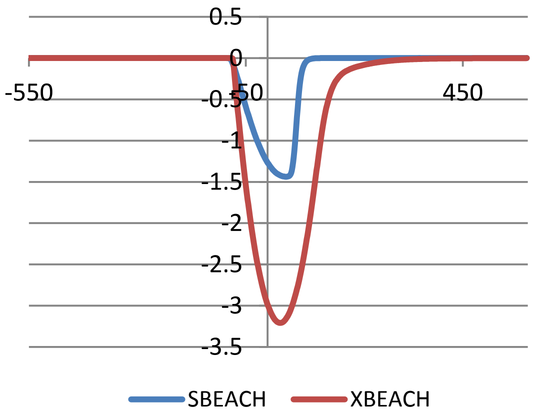
Run 2.3



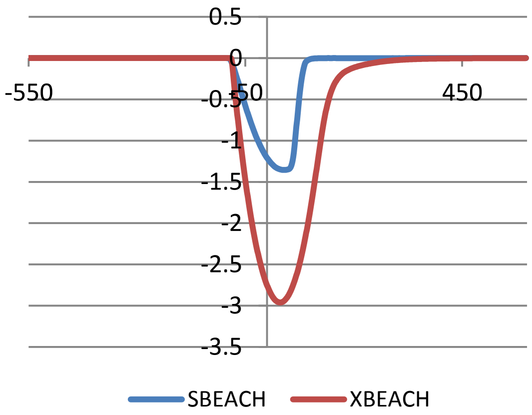
Run 2.4



Run 2.5



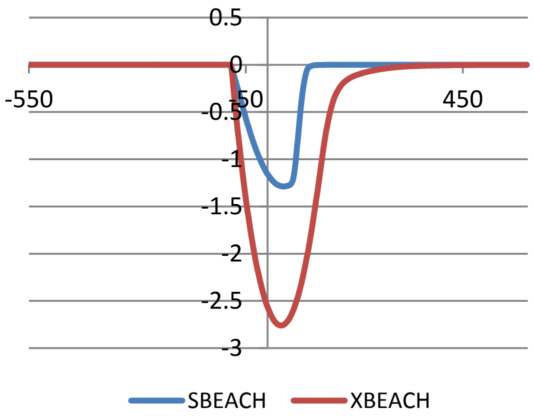
Run 2.6



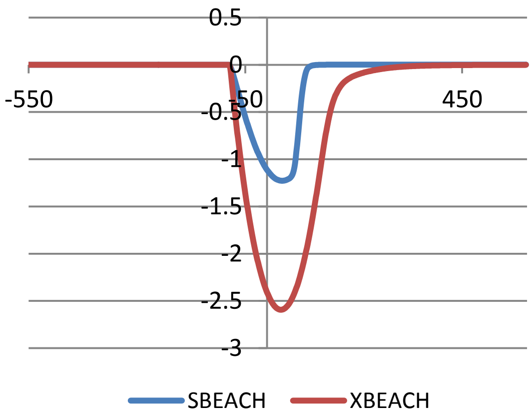
Distance from Mean Sea Level (m)

Sediment Transport Rate ($m^3/m/h$)

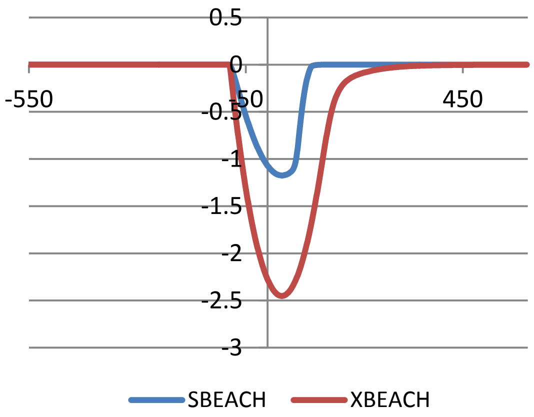
Run 2.7



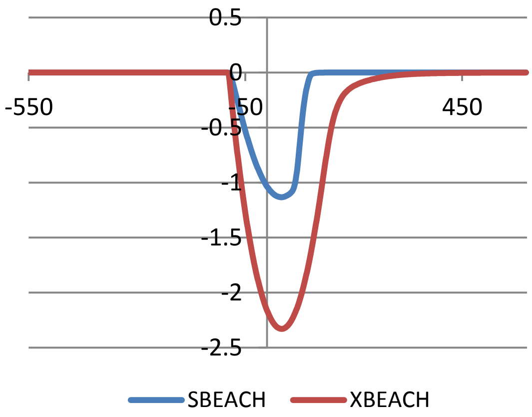
Run 2.8



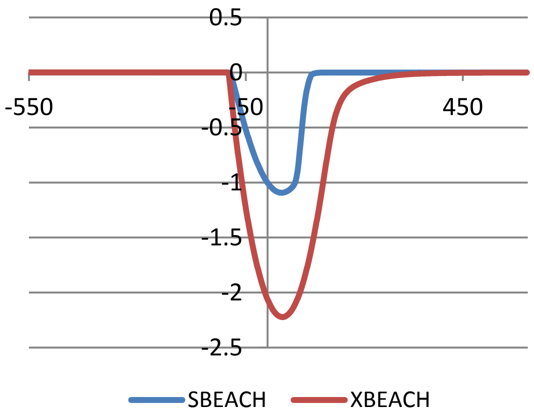
Run 2.9



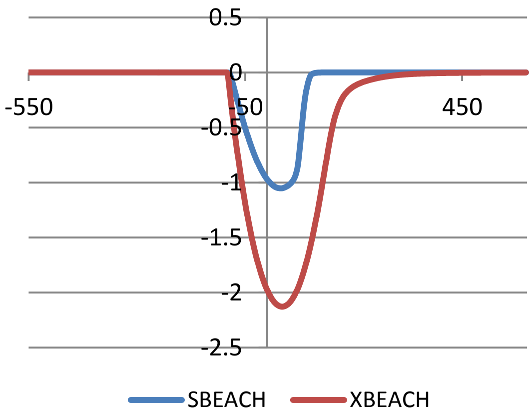
Run 2.10

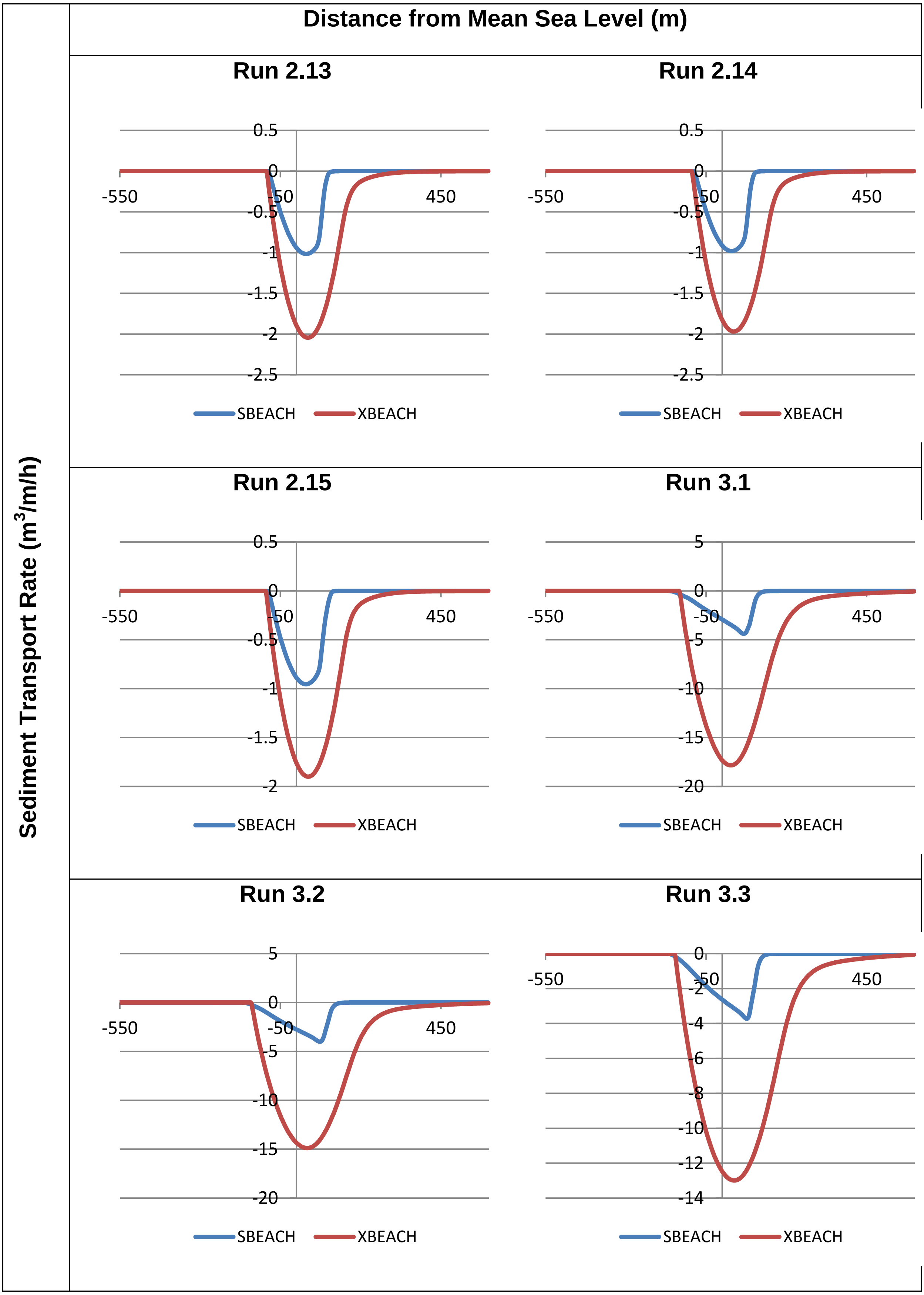


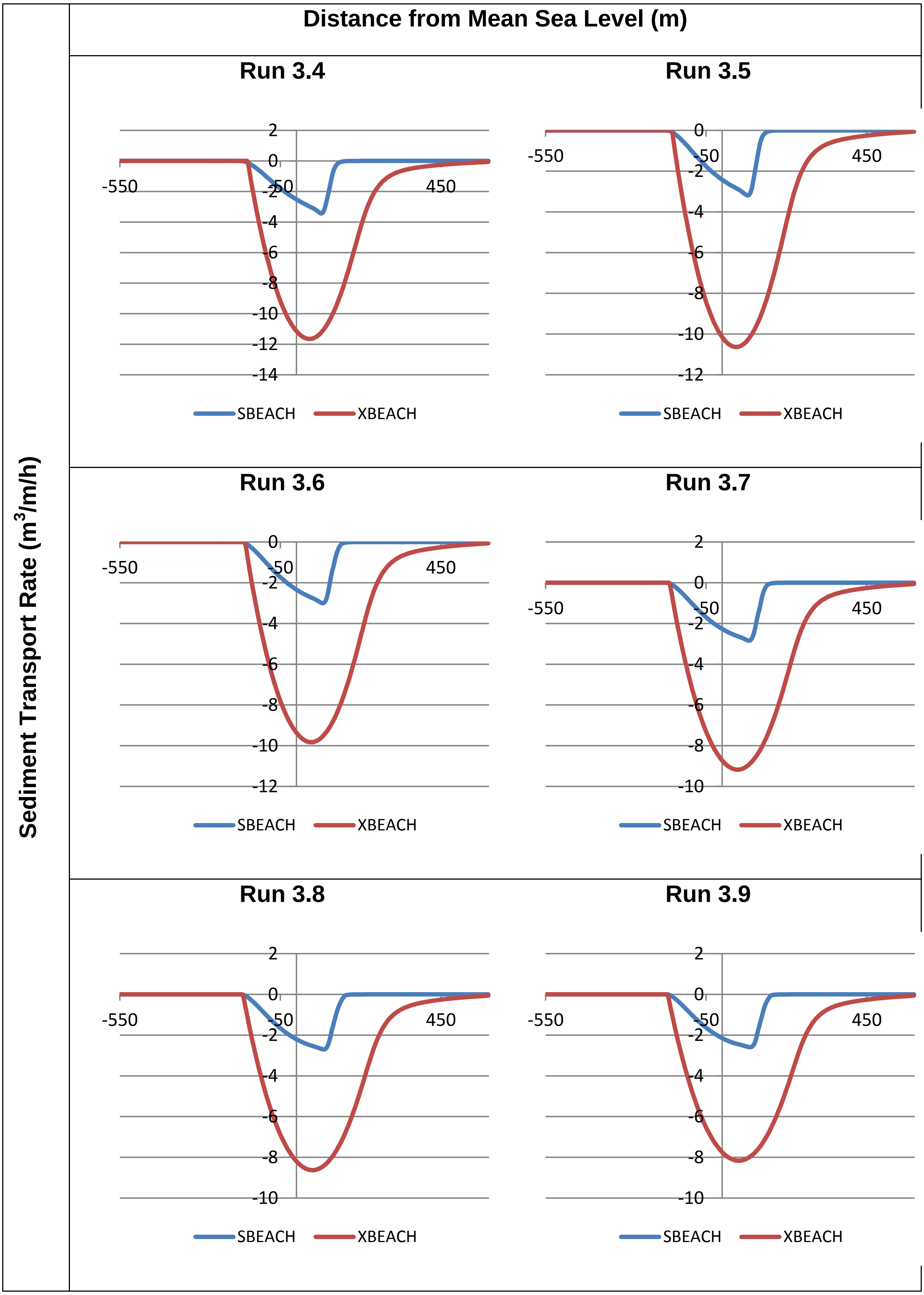
Run 2.11

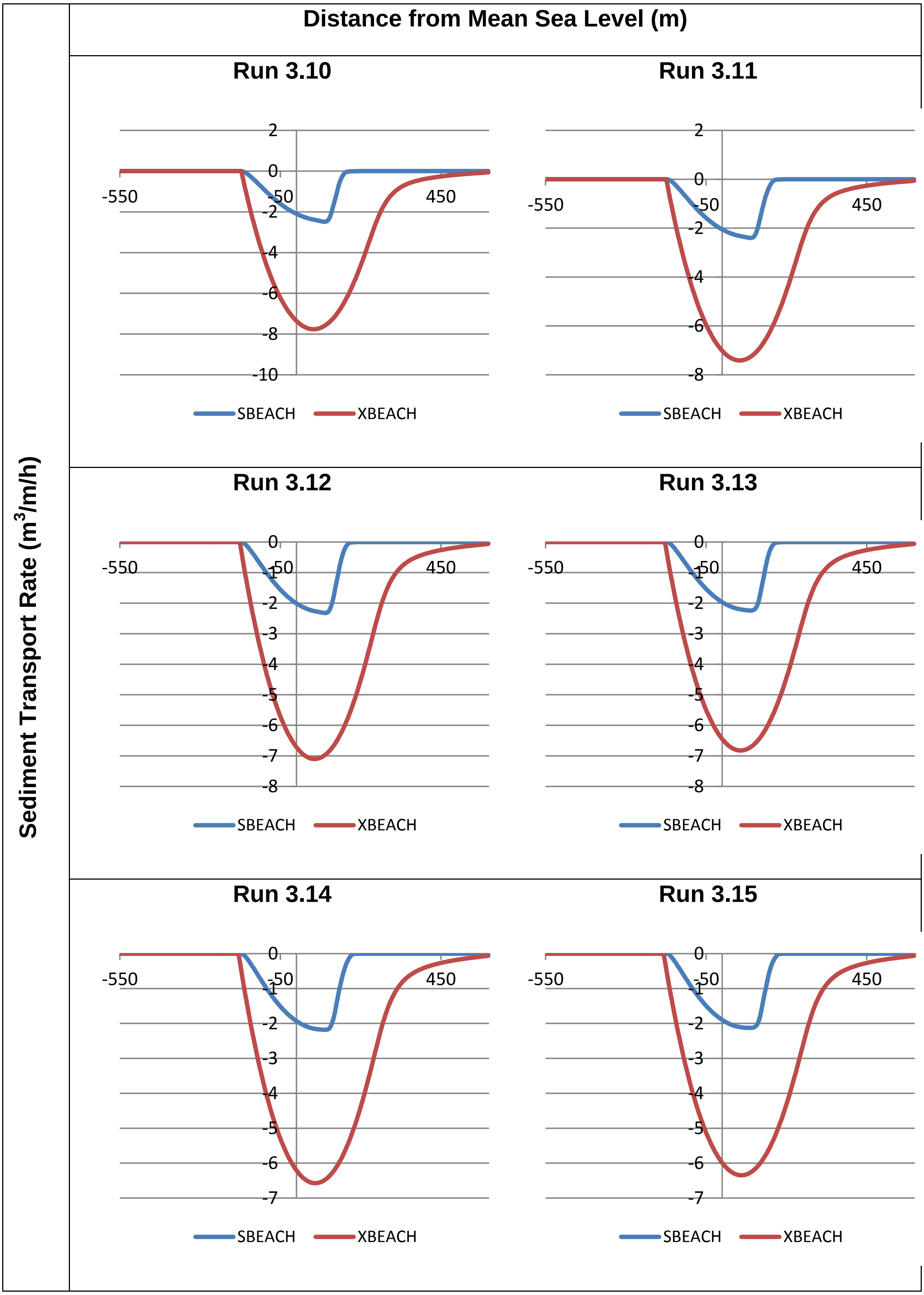


Run 2.12




Distance from Mean Sea Level (m)
Sediment Transport Rate (m³/m/h)
Run 2.13
0.5
0
-0.5
-1
-1.5
-2
-2.5
-550
-50
450
SBEACH
XBEACH
Run 2.14
0.5
0
-0.5
-1
-1.5
-2
-2.5
-550
-50
450
SBEACH
XBEACH
Run 2.15
0.5
0
-0.5
-1
-1.5
-2
-550
-50
450
SBEACH
XBEACH
Run 3.1
5
0
-5
-10
-15
-20
-550
-50
450
SBEACH
XBEACH
Run 3.2
5
0
-5
-10
-15
-20
-550
-50
450
SBEACH
XBEACH
Run 3.3
0
-2
-4
-6
-8
-10
-12
-14
-550
-50
450
SBEACH
XBEACH


Distance from Mean Sea Level (m)
Sediment Transport Rate (m³/m/h)
Run 3.4
2
0
-2
-4
-6
-8
-10
-12
-14
-550
-50
450
SBEACH
XBEACH
Run 3.5
0
-2
-4
-6
-8
-10
-12
-550
-50
450
SBEACH
XBEACH
Run 3.6
0
-2
-4
-6
-8
-10
-12
-550
-50
450
SBEACH
XBEACH
Run 3.7
2
0
-2
-4
-6
-8
-10
-550
-50
450
SBEACH
XBEACH
Run 3.8
2
0
-2
-4
-6
-8
-10
-550
-50
450
SBEACH
XBEACH
Run 3.9
2
0
-2
-4
-6
-8
-10
-550
-50
450
SBEACH
XBEACH


Distance from Mean Sea Level (m)
Sediment Transport Rate (m3/m/h)
Run 3.10
2
0
-2
-4
-6
-8
-10
-550
-50
450
SBEACH
XBEACH
Run 3.11
2
0
-2
-4
-6
-8
-550
-50
450
SBEACH
XBEACH
Run 3.12
0
-1
-2
-3
-4
-5
-6
-7
-8
-550
-50
450
SBEACH
XBEACH
Run 3.13
0
-1
-2
-3
-4
-5
-6
-7
-8
-550
-50
450
SBEACH
XBEACH
Run 3.14
0
-1
-2
-3
-4
-5
-6
-7
-550
-50
450
SBEACH
XBEACH
Run 3.15
0
-1
-2
-3
-4
-5
-6
-7
-550
-50
450
SBEACH
XBEACH

APPENDIX C: LONG WAVE SENSITIVITY

Appendix C-1: Model Runs to Evaluate Sensitivity to Long Waves

Run	Monochromatic Short Waves		Free Long Waves		Water Elevation Above MSL (m)	Duration (h)
	Height (m)	Period (s)	Height (m)	Period (s)		
F.1.1	0.8	6	-	-	0	4
F.1.2	0.8	6	0.08	30	0	4
F.1.3	0.8	6	0.08	110	0	4
F.1.4	0.8	6	0.08	200	0	4
F.2.1	3	12	-	-	0	4
F.2.2	3	12	0.3	30	0	4
F.2.3	3	12	0.3	110	0	4
F.2.4	3	12	0.3	200	0	4
F.3.1	6	16	-	-	0	4
F.3.2	6	16	0.6	30	0	4
F.3.3	6	16	0.6	110	0	4
F.3.4	6	16	0.6	200	0	4

Run	Monochromatic Short Waves		Bound Long Waves	Water Elevation Above MSL (m)	Duration (h)
	Height (m)	Period (s)	Period (s)		
B.1.1	0.8	6	-	0	4
B.1.2	0.8	6	30	0	4
B.1.3	0.8	6	110	0	4
B.1.4	0.8	6	200	0	4
B.2.1	3	12	-	0	4
B.2.2	3	12	30	0	4
B.2.3	3	12	110	0	4
B.2.4	3	12	200	0	4
B.3.1	6	16	-	0	4
B.3.2	6	16	30	0	4
B.3.3	6	16	110	0	4
B.3.4	6	16	200	0	4

Appendix C-2A: Free Long Wave Sensitivity Model Configuration/Parameter Setups

****
* SBEACH model configuration file: FLW1.2.CFG *
****

A--------------------------- MODEL SETUP ------------------------------A
A.1 RUN TITLE: TITLE
FLW 1.2: Free long wave 0.08m and 30s

A.2 INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS
1

A.3 TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY RELATIVE TO INITIAL PROFILE: NDX, XSTART
766 -550.0

A.4 GRID TYPE (CONSTANT=0, VARIABLE=1): IDX
0

A.5 COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6 CONSTANT GRID CELL WIDTH: DXC
1.5

A.7 COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8 NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID
4

A.9 GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)
(10, 2) (1, 38) (1, 800) (10, 50)

A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT
5761 0.04167

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR
1

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)
720

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP
0

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH WILL BE DETERMINED): ELV1, ELV2, ELV3
10.00 3.00 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED
EDP1, EDP2, EDP3, REFELV
10.00 5.00 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K
1.75E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS
0.002000

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM
0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC
20.00

B---------------------- WAVES/WATER ELEVATION/WIND -----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE
1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE
0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T
0.8 6.00

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV
60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG
0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN
0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG
0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS
0.00

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND
0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC
7878 20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV
1

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV
2.00

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV
0.041667

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND
0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND
0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND
0.00

C------------------------------- BEACH -----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN
1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,
LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,
END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,
XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS
0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS
0.30

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50
0.25

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX
20.00

D------------------------------ BEACH FILL --------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL
0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE
TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START
AND END OF BEACH FILL: NFILL
0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE
INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E--------------------------- SEAWALL/REVETMENT ----------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL
0
E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.
E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL
0.00
E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL
0
E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.
E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION
AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES
FAILURE: PEFAIL, WEFAIL,HFAIL
0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F
---------------------------------- END -----------------------------------

```
%%% XBeach parameter settings input file %%%
%%% date: 06-Aug-2016 12:00 %%%
%%% function: xb_write_params %%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%xbeach/delft3d
gridform = xbeach
depfile = DepSeaLevel.dep
posdwn = -1
alfa = 0
dx = 1.5
dy = 0
nx = 765
ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
thetamin = -90
thetamax = +90
dtheta = 10
thetanaut = 0

%%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tstart = 0
tstop = 14400
tintg = 60
tintp = 60

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
rho = 1025
g = 9.81
D50 = 0.00025
rhos = 2650
por = 0.3

%%% Flow boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
front = abs_1d
back = abs_1d
left = 0
right = 0

%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tideloc = 1
zs0file = tide.txt

%%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
instat = 0
Hrms = 0.8
Trep = 6
lwave = 0
```

%%% Morphology Conditions %%
morfac = 1
morstart = 0

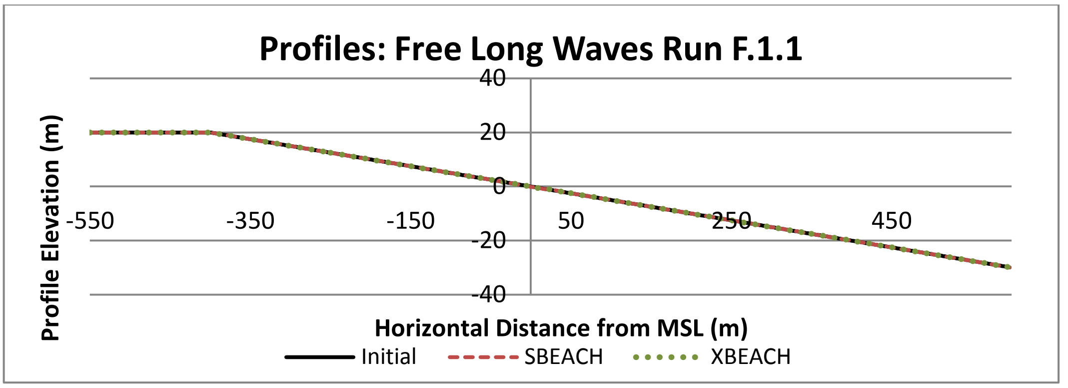
%%% Output variables %%
outputformat = netcdf
nglobalvar = 6
zb
zb0
zs
H
hh
Qb
nmeanvar = 3
H
hh
zs

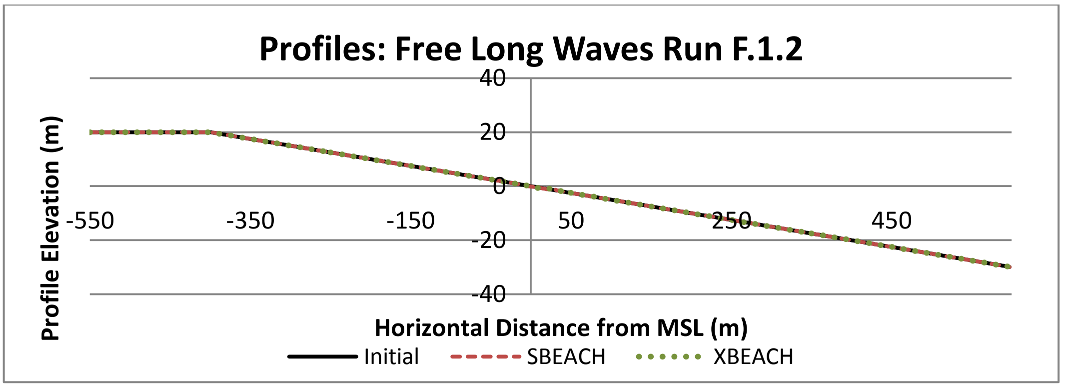
Appendix C-2B: Bound Long Wave Sensitivity Model Configuration/Parameter Setups

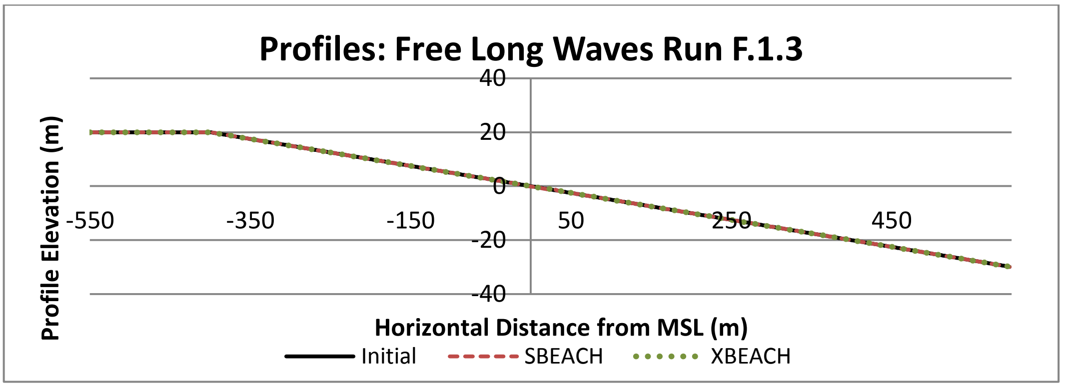
```
%%% XBeach parameter settings input file %%%
%%% %%%
%%% date: 06-Aug-2016 12:00 %%%
%%% function: xb_write_params %%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%xbeach/delft3d
gridform = xbeach

depfile = DepSeaLevel.dep
posdwn = -1
alfa = 0
dx = 1.5
dy = 0
nx = 765
ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90
thetamax = +90
dtheta = 10
thetanaut = 0

%%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tstart = 0
tstop = 14400
tintg = 60
tintp = 60

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rho = 1025
g = 9.81
D50 = 0.00025
rhos = 2650
por = 0.3
```

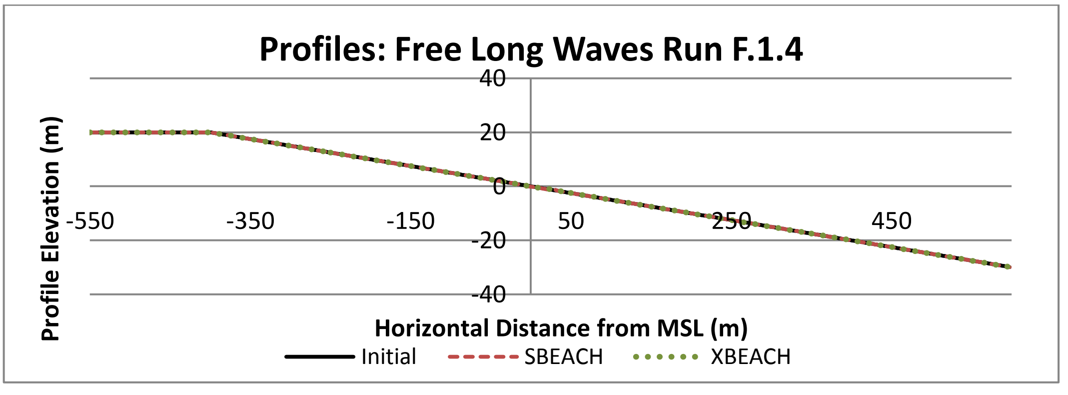
```
%%% Flow boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

front = abs_1d
back = abs_1d
left = 0
right = 0

%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tideloc = 0
zs0 = 0

%%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% %%

instat = 1
Hrms = 0.8
Trep = 6
Tlong = 30
lwave = 1

%%% Morphology Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

morfac = 1
morstart = 0

%%% Output variables %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

outputformat = netcdf


nglobalvar = 6
zb
zb0
zs
H
hh
Qb

nmeanvar = 3
H
hh
zs
```

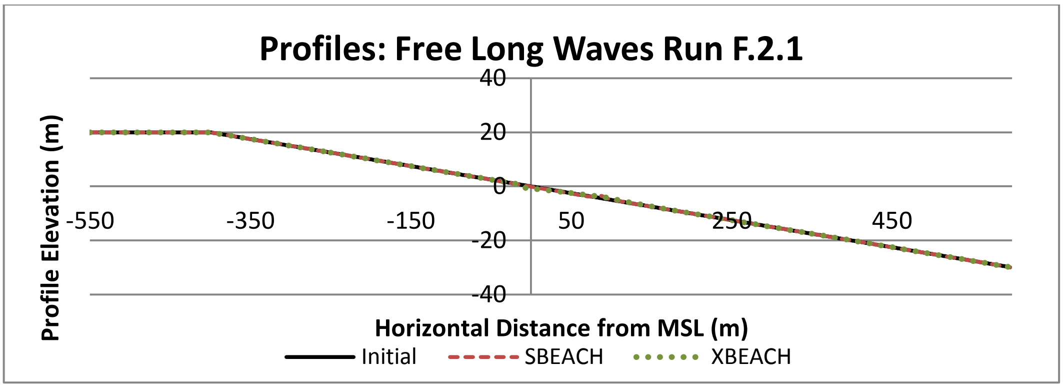
Appendix C-3: Initial and Final Beach Profiles for Long Wave Model Runs

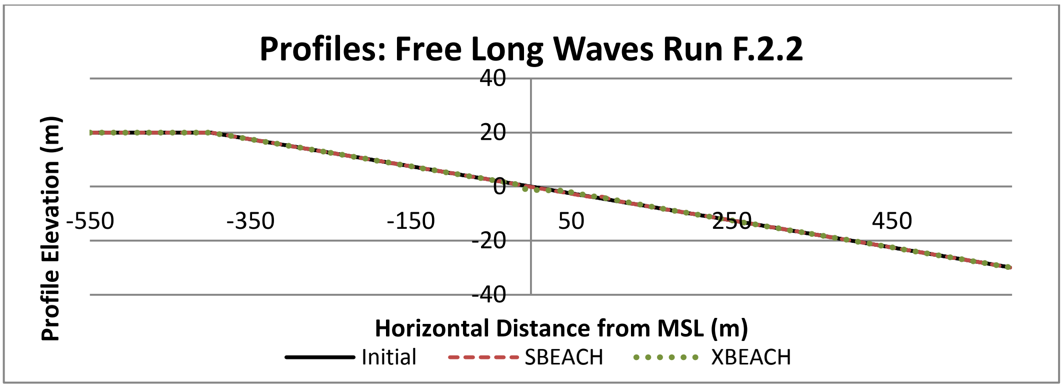


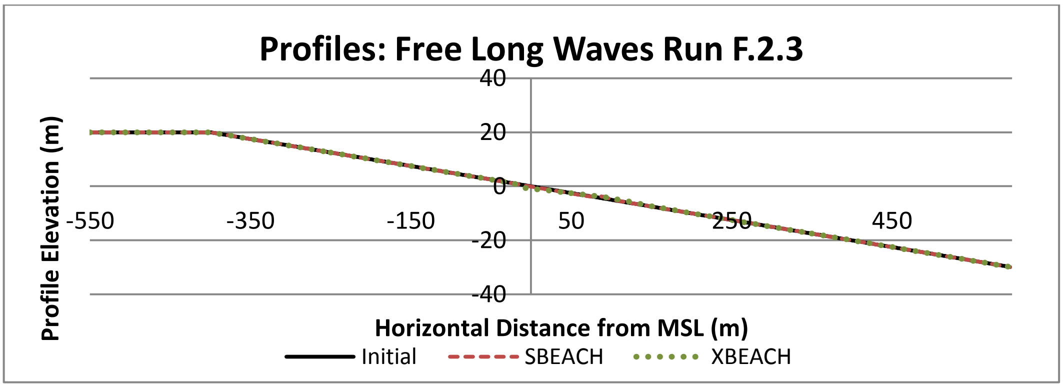







Profiles: Free Long Waves Run F.2.1
Profile Elevation (m)
40
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.2.2
Profile Elevation (m)
40
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.2.3
Profile Elevation (m)
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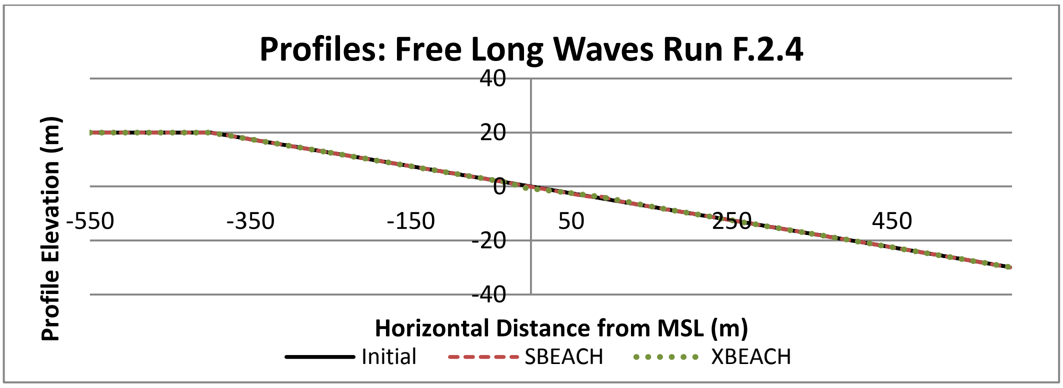
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.2.4
Profile Elevation (m)
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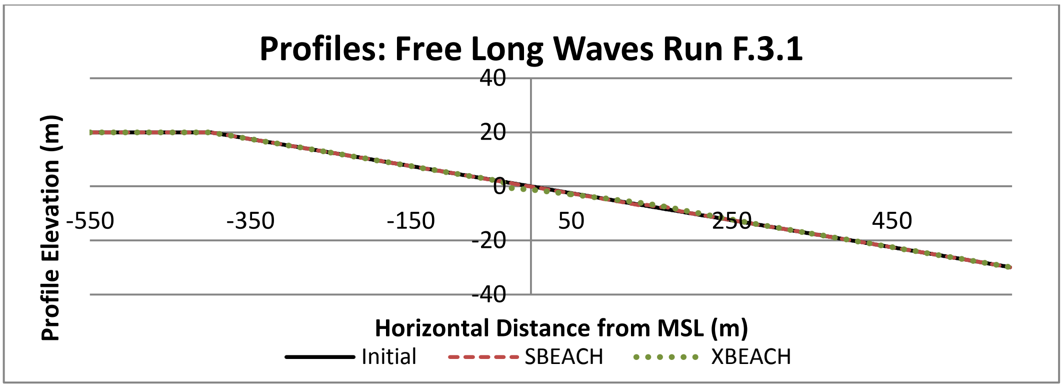
50
250
450
Horizontal Distance from MSL (m)
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.3.1
Profile Elevation (m)
Horizontal Distance from MSL (m)
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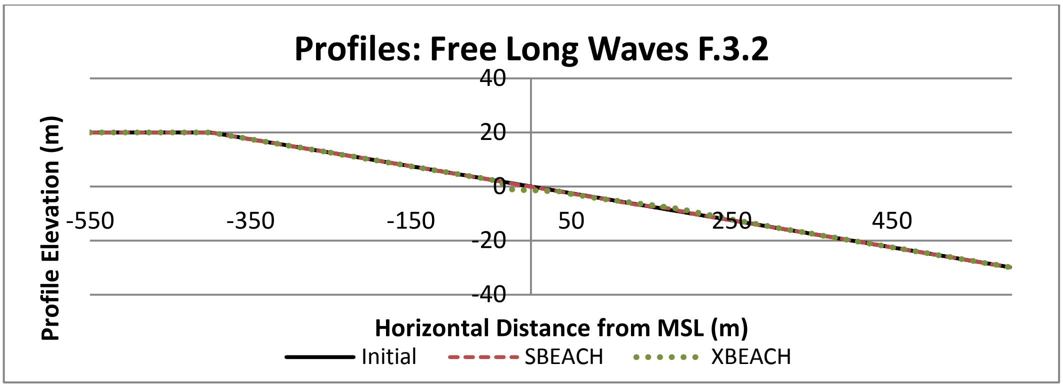
20
0
-20
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Free Long Waves F.3.2
Profile Elevation (m)
Horizontal Distance from MSL (m)
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-40
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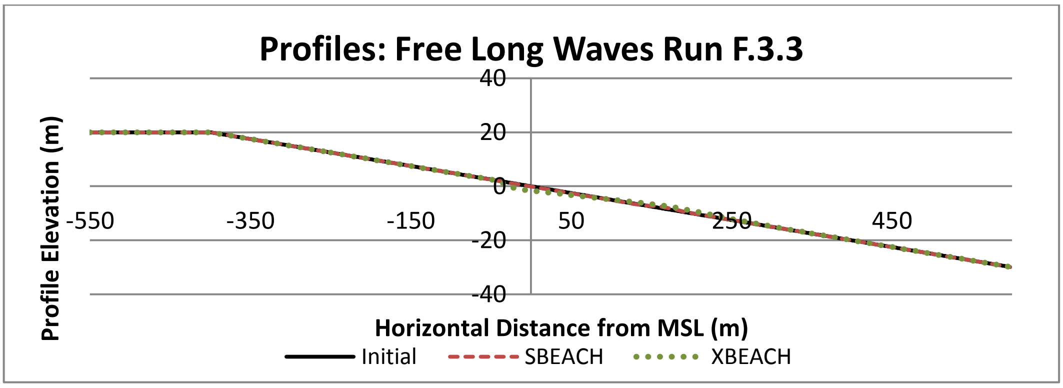
250
450
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.3.3
Profile Elevation (m)
Horizontal Distance from MSL (m)
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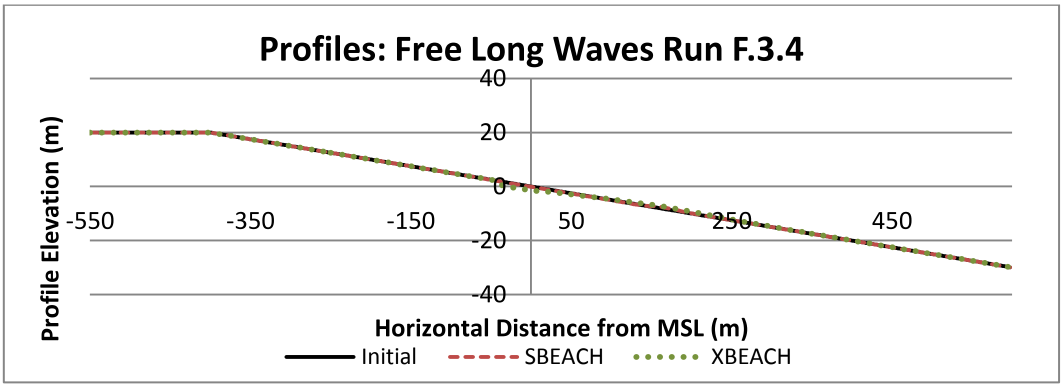
20
0
-20
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Free Long Waves Run F.3.4
Profile Elevation (m)
Horizontal Distance from MSL (m)
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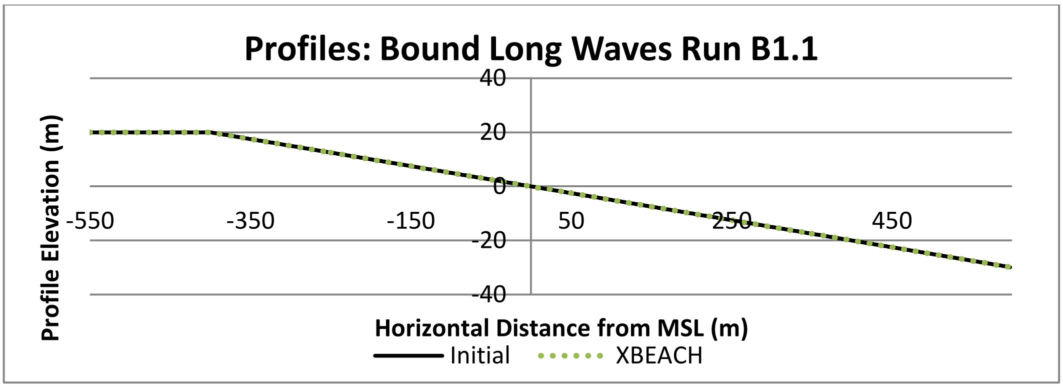
20
0
-20
-40
-550
-350
-150
50
250
450
Initial
SBEACH
XBEACH


Profiles: Bound Long Waves Run B1.1
Profile Elevation (m)
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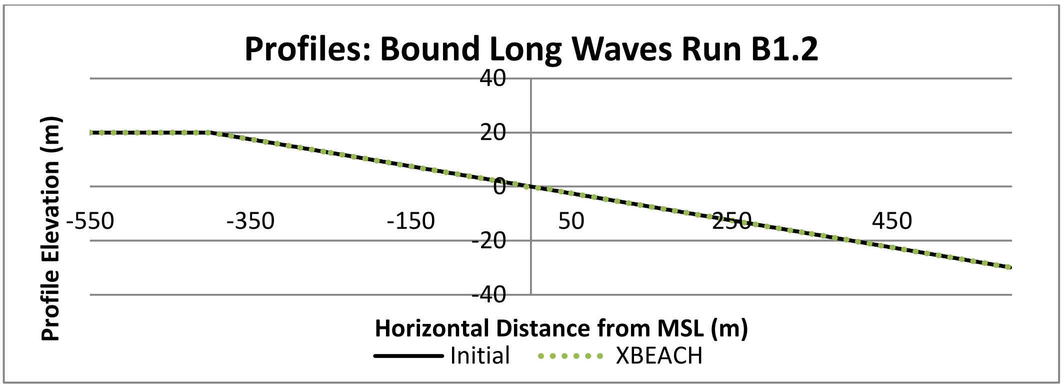
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B1.2
Profile Elevation (m)
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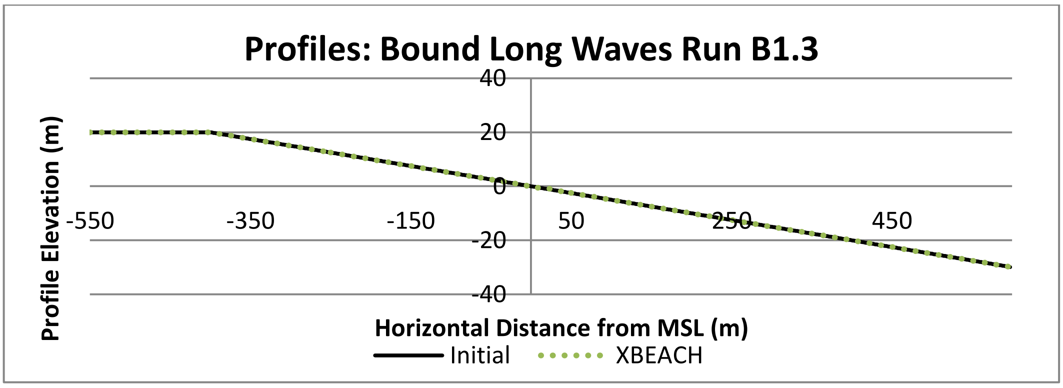
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B1.3
Profile Elevation (m)
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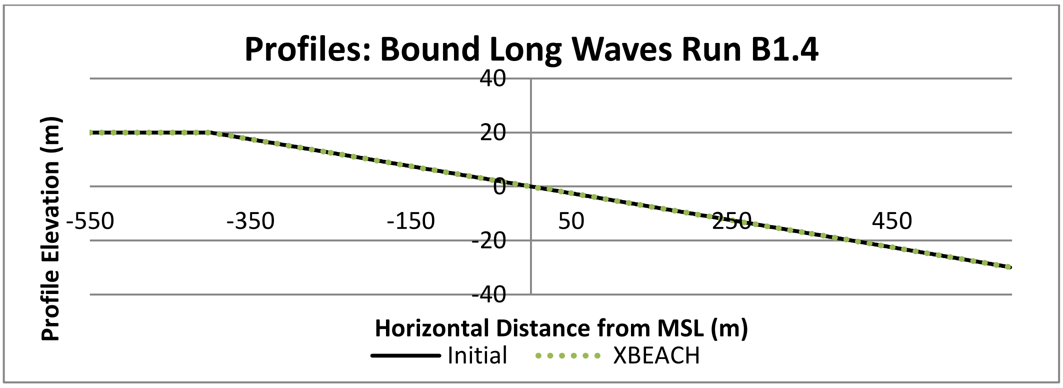
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B1.4
Profile Elevation (m)
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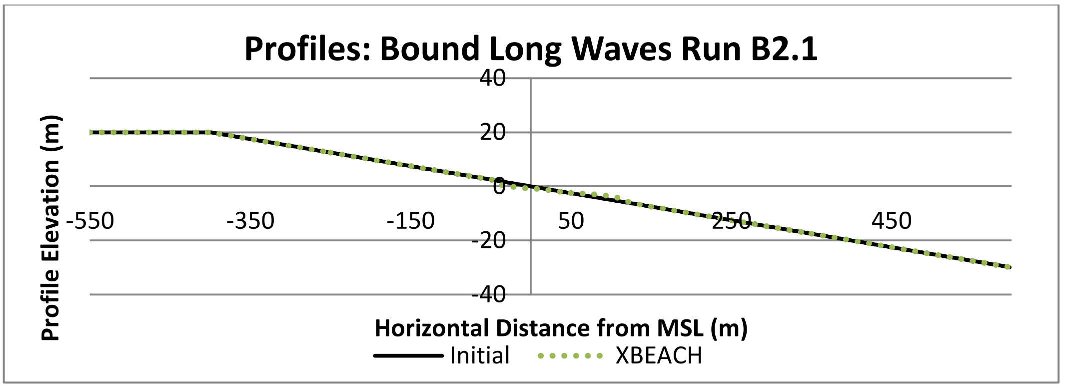
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B2.1
Profile Elevation (m)
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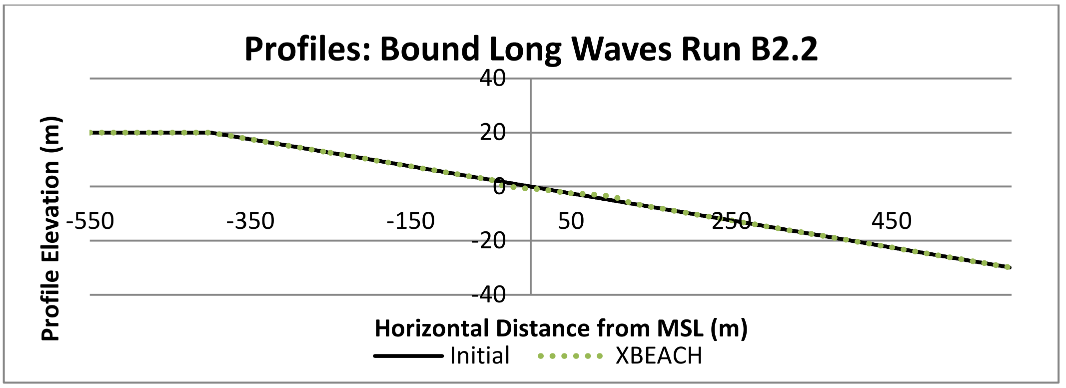
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B2.2
Profile Elevation (m)
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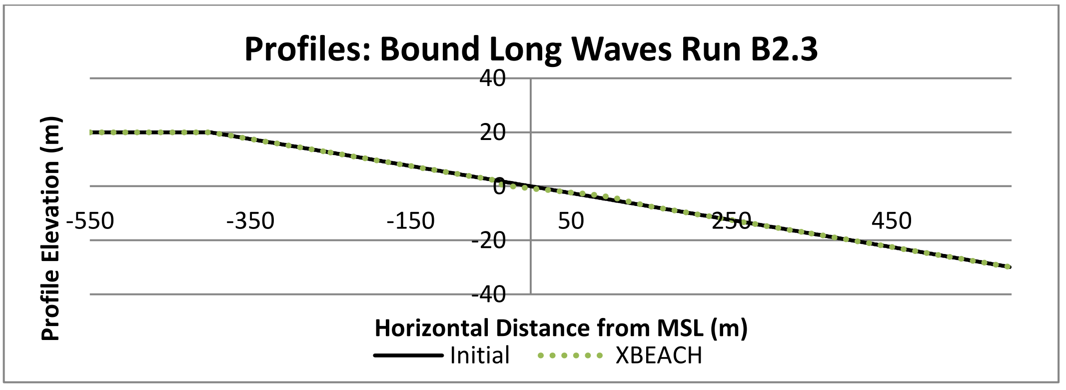
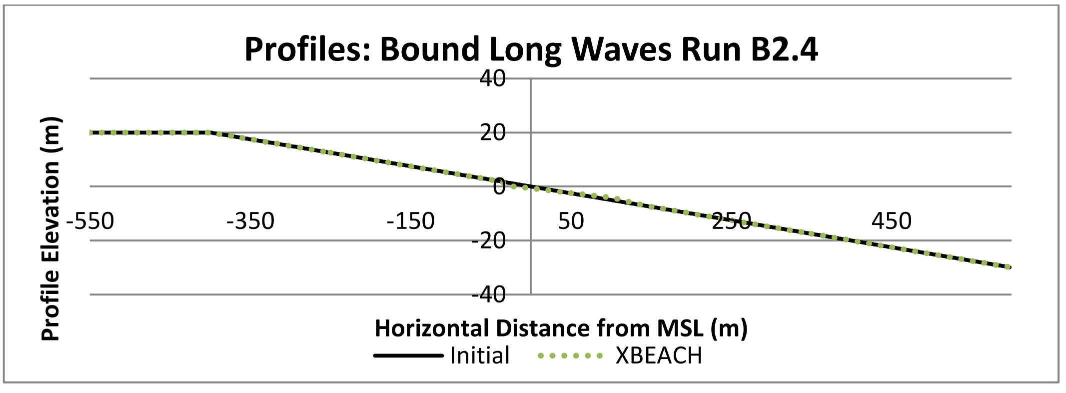
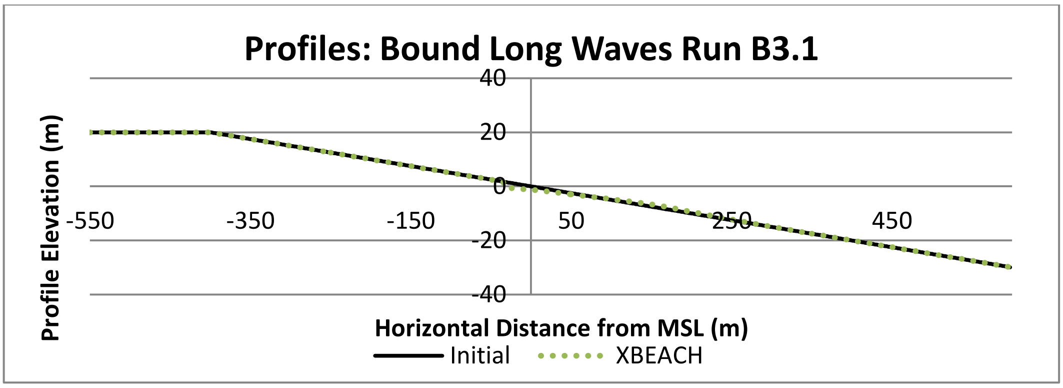
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B2.3
Profile Elevation (m)
40
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B2.4
Profile Elevation (m)
40
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B3.1
Profile Elevation (m)
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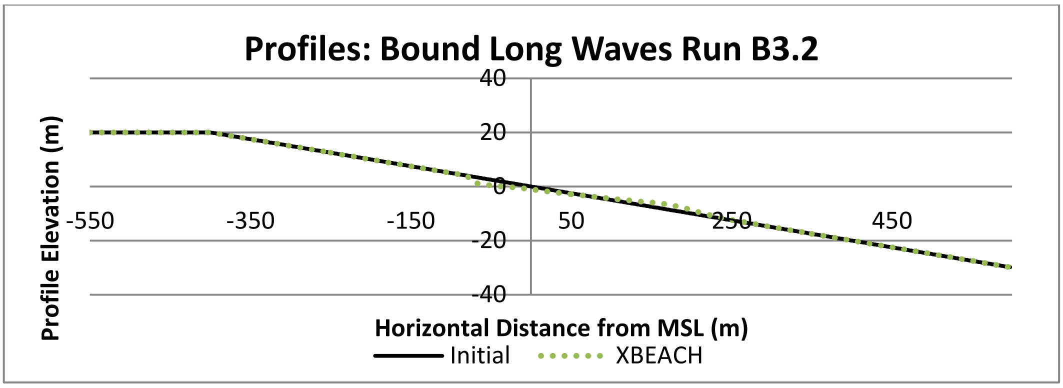
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B3.2
Profile Elevation (m)
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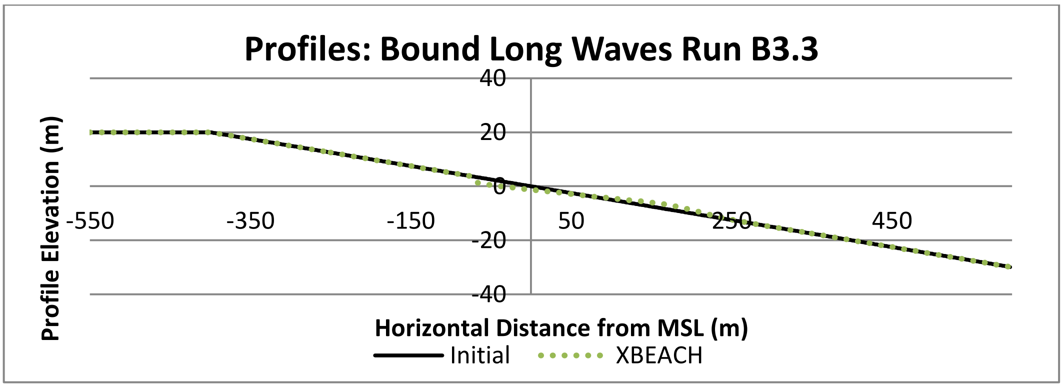
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B3.3
Profile Elevation (m)
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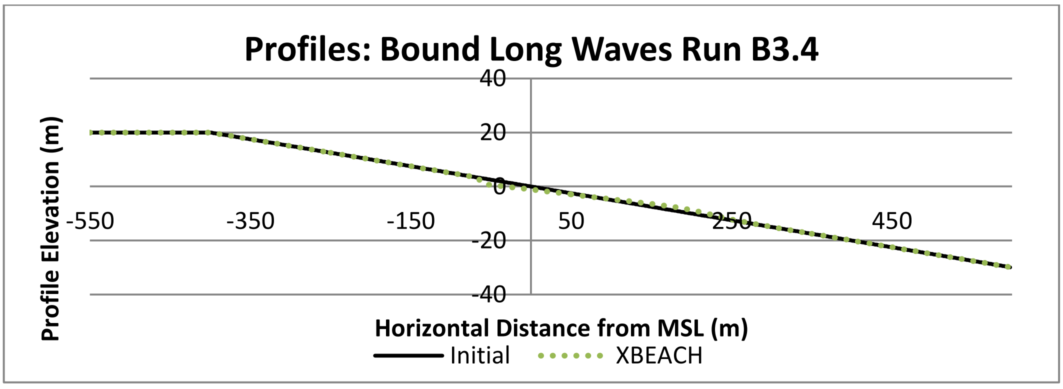
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH


Profiles: Bound Long Waves Run B3.4
Profile Elevation (m)
40
20
0
-20
-40
-550
-350
-150
50
250
450
Horizontal Distance from MSL (m)
Initial
XBEACH

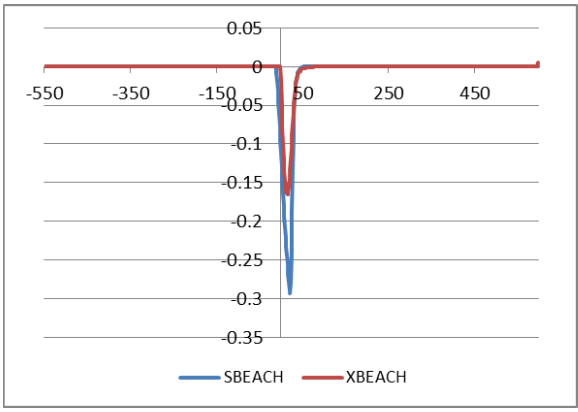
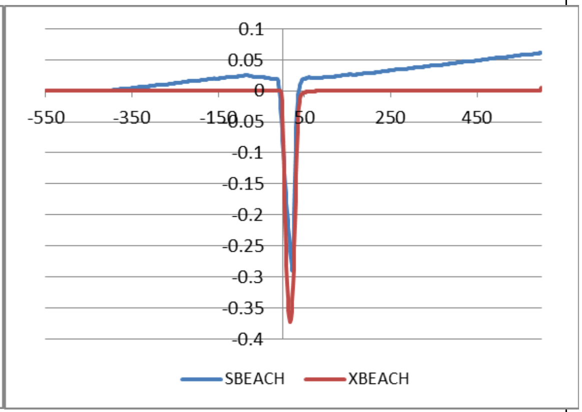
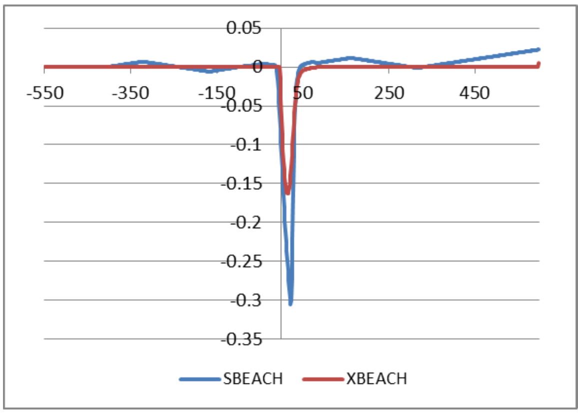
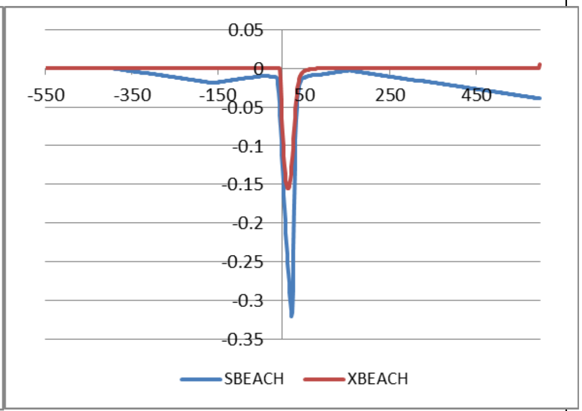
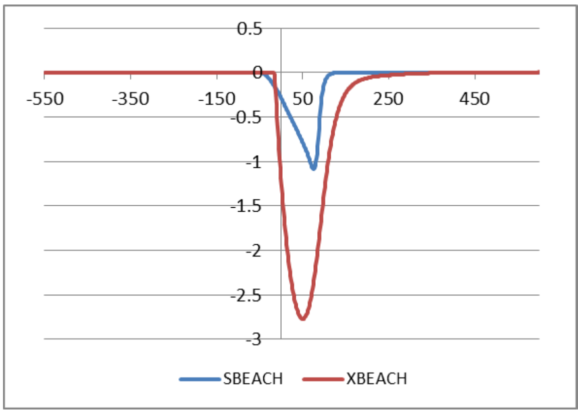
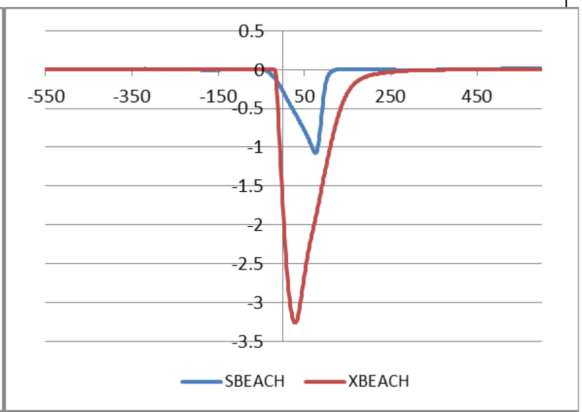
Appendix C-4: Long Wave Sensitivity Comparison Parameters

Run	Absolute Displaced Sediment Volumes (m^3/m)			Eroded Volume of Sediment Above Water Level (m^3/m)			Shoreline Recession (m)		
	SB	XB	DR	SB	XB	DR	SB	XB	DR
F.1.1	7.04	4.01	-	1.27	0.14	-	2.63	0.74	-
F.1.2	8.37	9.00	-	1.09	0.80	-	2.77	2.75	-
F.1.3	8.33	3.96	-	1.29	0.69	-	2.77	2.97	-
F.1.4	8.31	3.79	-	1.47	0.92	-	2.77	4.13	-
F.2.1	26.03	66.61	-	3.46	14.90	-	2.25	14.75	-
F.2.2	26.79	78.18	-	3.37	21.52	-	2.44	15.95	-
F.2.3	26.70	79.13	-	3.53	17.22	-	2.44	16.38	-
F.2.4	26.70	69.33	-	3.73	17.58	-	2.44	17.93	-
F.3.1	41.54	207.12	-	5.25	55.45	-	2.06	32.50	-
F.3.2	39.42	208.92	-	4.98	67.66	-	2.01	31.94	-
F.3.3	39.35	266.03	-	4.97	57.42	-	2.01	30.38	-
F.3.4	39.30	222.30	-	5.34	59.20	-	2.01	31.74	-
B.1.1	-	4.01	-	-	0.14	-	-	0.74	-
B.1.2	-	7.05	-	-	2.05	-	-	5.84	-
B.1.3	-	6.95	-	-	1.68	-	-	4.64	-
B.1.4	-	6.38	-	-	1.24	-	-	3.41	-
B.2.1	-	131.49	-	-	51.35	-	-	29.01	-
B.2.2	-	131.49	-	-	51.35	-	-	27.47	-
B.2.3	-	112.93	-	-	42.00	-	-	23.42	-
B.2.4	-	93.99	-	-	32.22	-	-	21.10	-
B.3.1	-	207.12	-	-	55.45	-	-	32.50	-
B.3.2	-	347.79	-	-	134.28	-	-	37.14	-
B.3.3	-	340.64	-	-	127.87	-	-	38.02	-
B.3.4	-	296.27	-	-	103.83	-	-	33.76	-

Appendix C-5: Long Wave Sensitivity Sediment Transport Rate Distributions

Distance from Mean Sea Level (m)

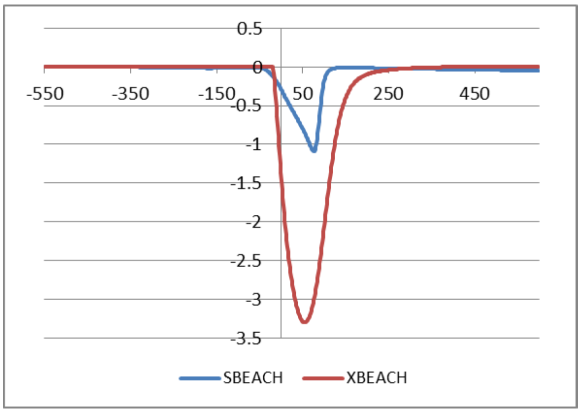
Sediment Transport Rate (m^3/m/h)

Run F.1.1	Run F.1.2
	
Run F.1.3	**Run F.1.4**
	
Run F.2.1	**Run F.2.2**
	

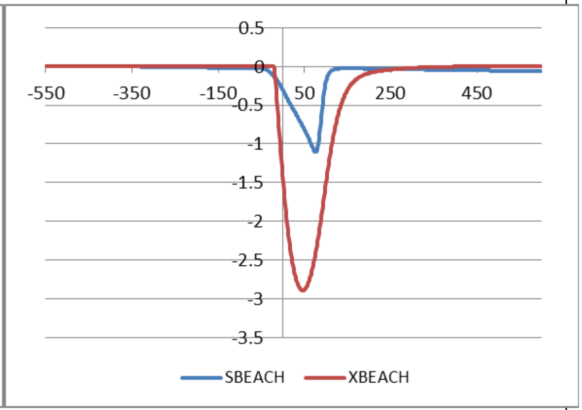
Distance from Mean Sea Level (m)

Sediment Transport Rate ($m^3/m/h$)

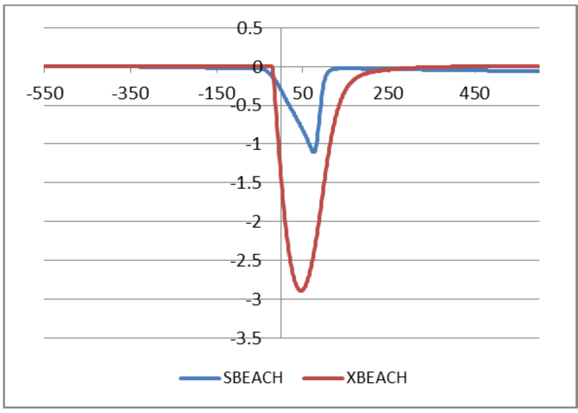
Run F.2.3



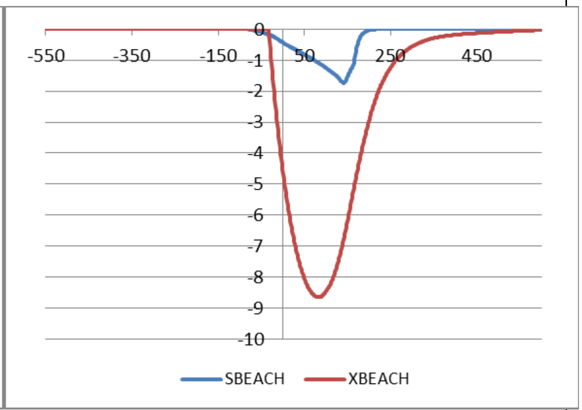
Run F.2.4



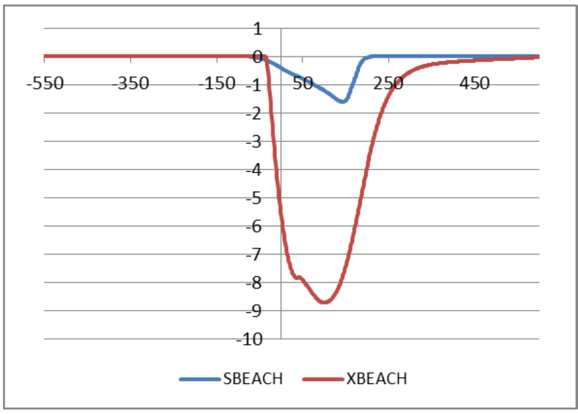
Run F.3.1



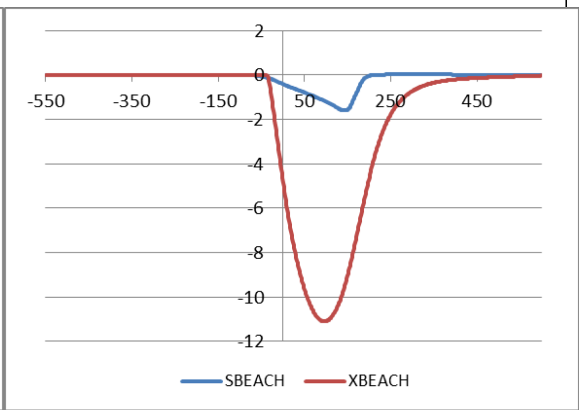
Run F.3.2



Run F.3.3



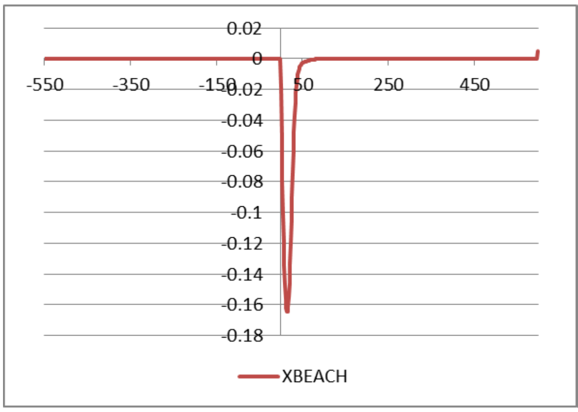
Run F.3.4



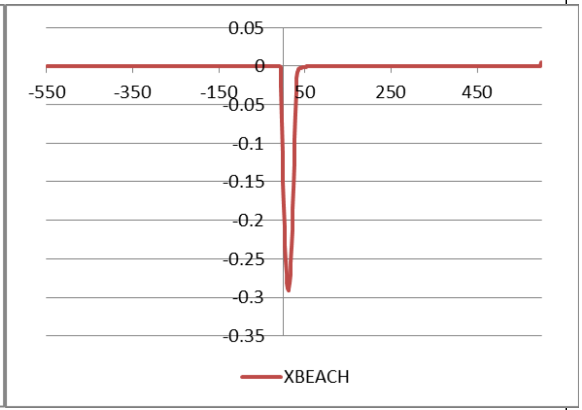
Sediment Transport Rate (m^3/m/h)

Distance from Mean Sea Level (m)

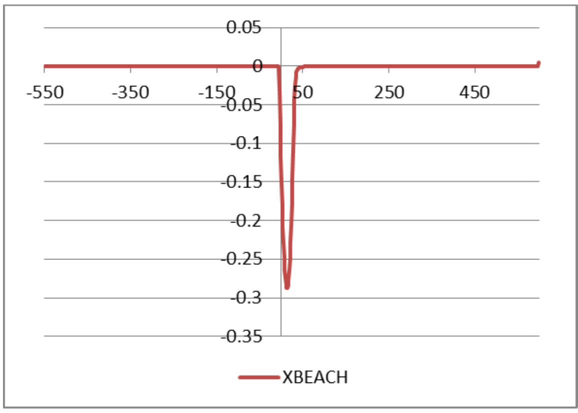
Run B.1.1



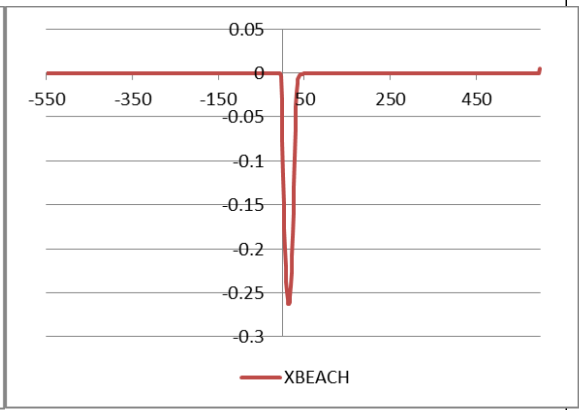
Run B.1.2



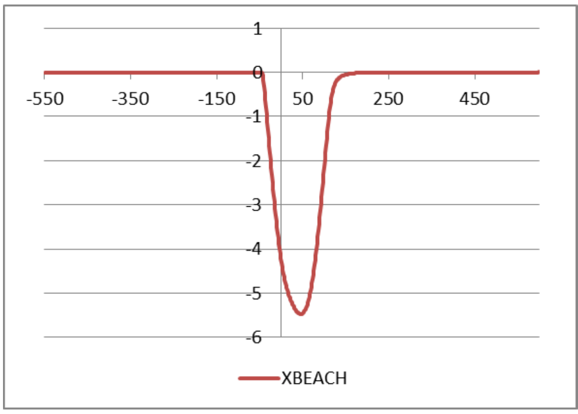
Run B.1.3



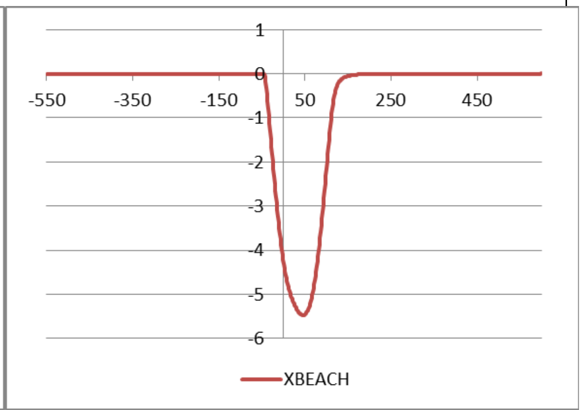
Run B.1.4



Run B.2.1



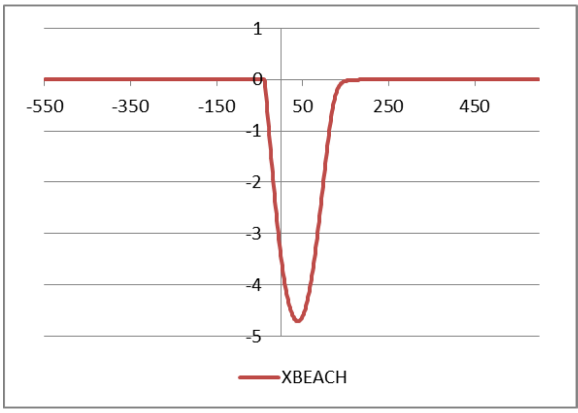
Run B.2.2



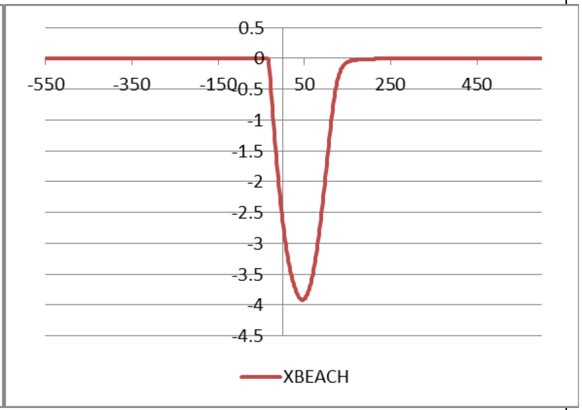
Sediment Transport Rate (m^3/m/h)

Distance from Mean Sea Level (m)

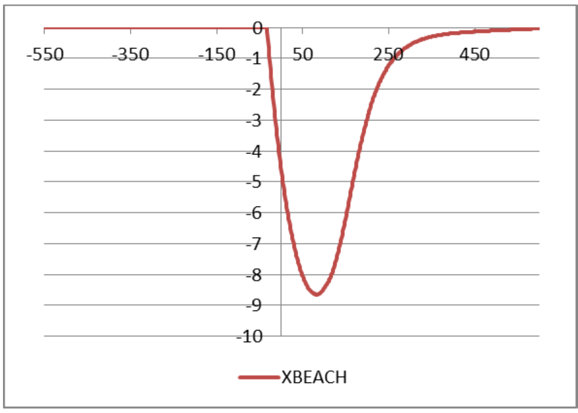
Run B.2.3



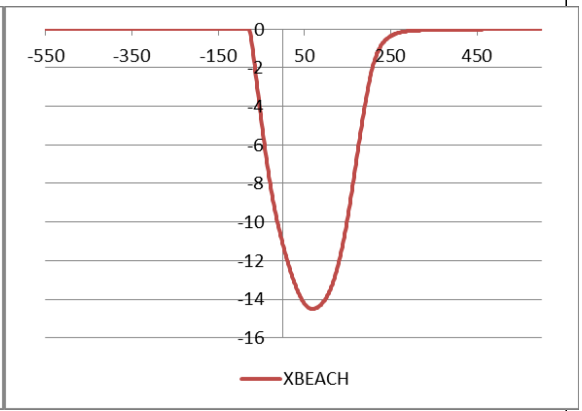
Run B.2.4



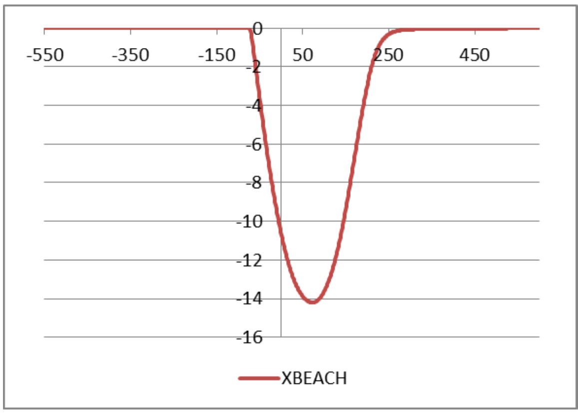
Run B.3.1



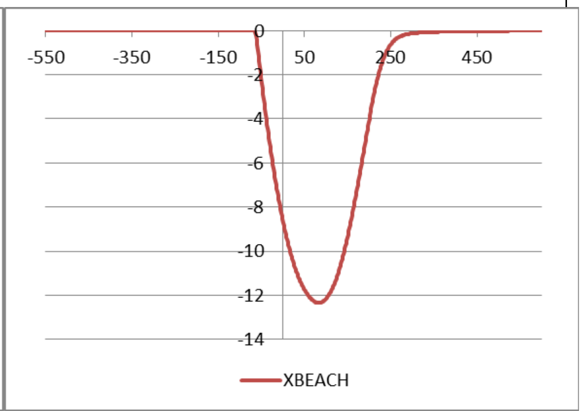
Run B.3.2



Run B.3.3



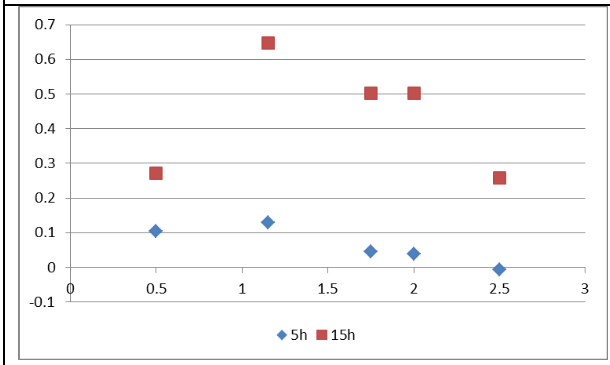
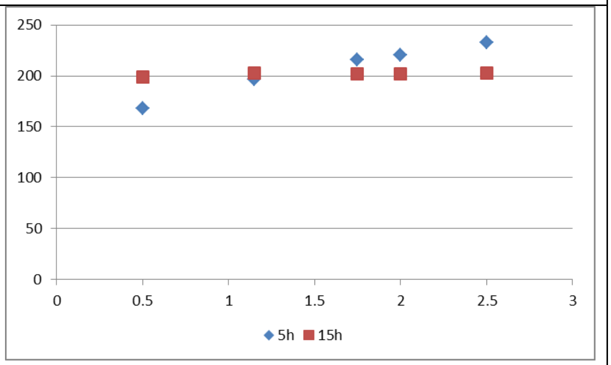
Run B.3.4



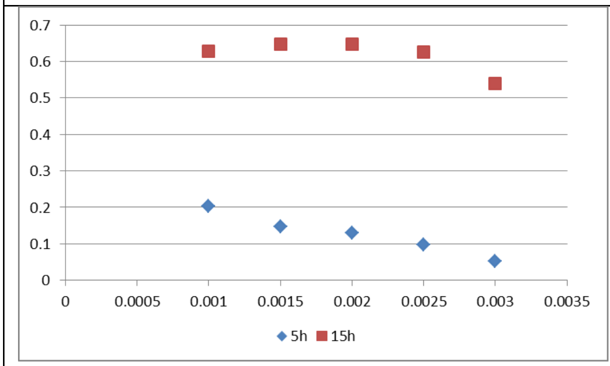
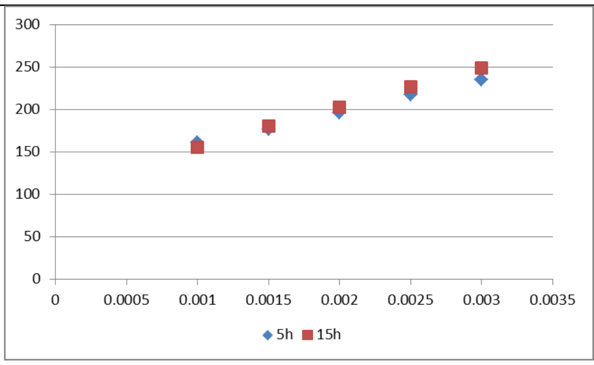
APPENDIX D: WATER LEVEL VARIATION ACCURACY

Appendix D-1: SBEACH Water Level Accuracy Calibration

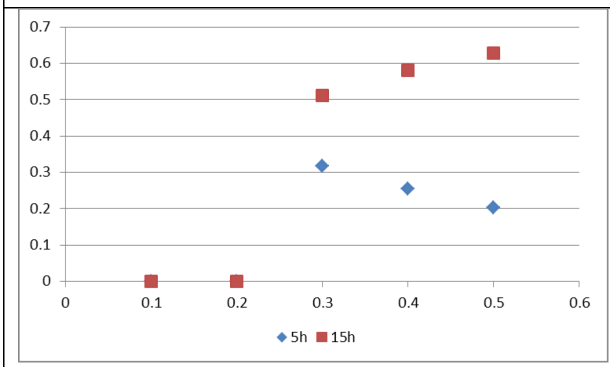
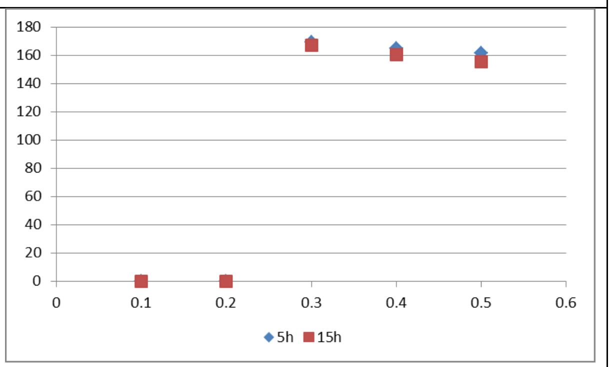
X: TRANSPORT RATE COEFFICIENT (m^4/N)

Y: BSS	Y: Eroded Volume %
	

X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

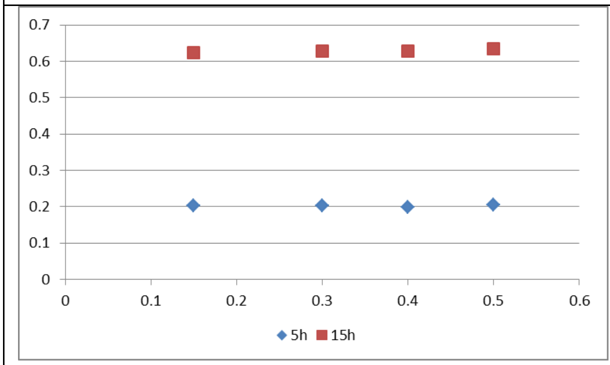
Y: BSS	Y: Eroded Volume %
	

X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

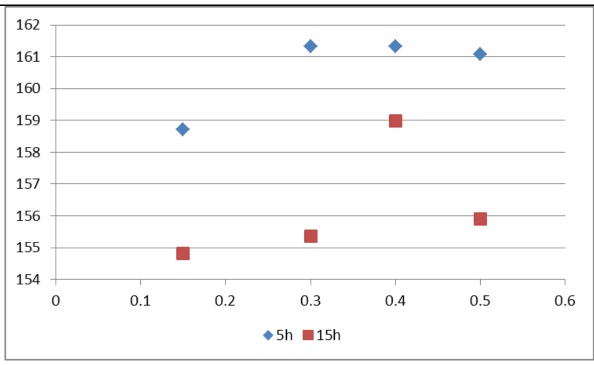
Y: BSS	Y: Eroded Volume %
	

X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)

Y: BSS

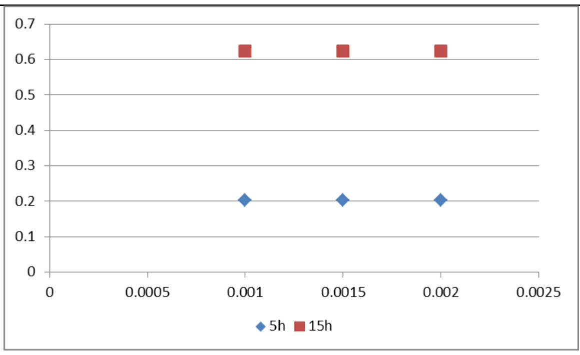


Y: Eroded Volume %

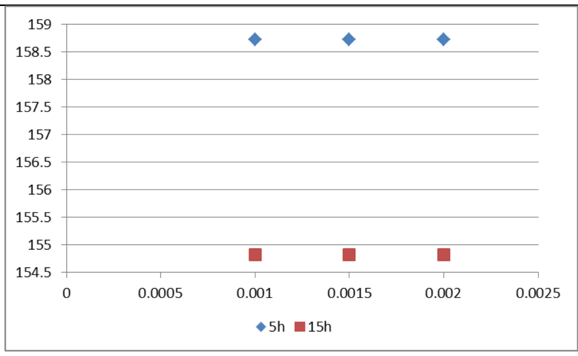


X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES

Y: BSS



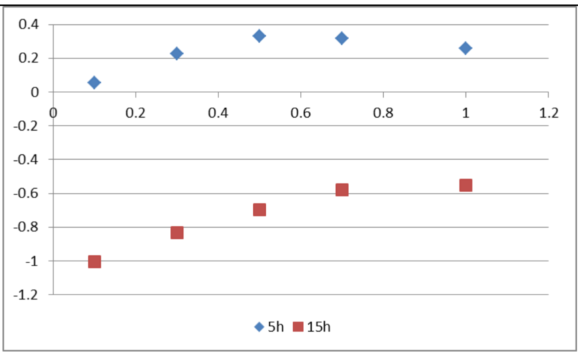
Y: Eroded Volume %



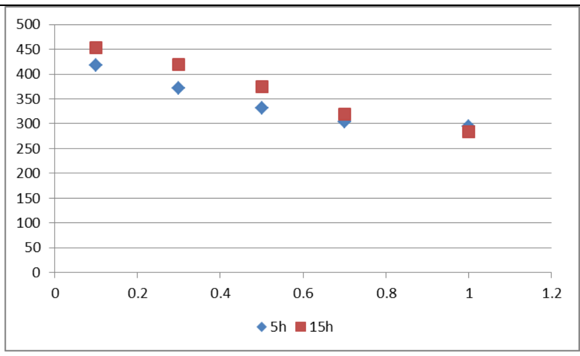
Appendix D-2: XBEACH Water Level Accuracy Calibration

X: wetslp

Y: BSS

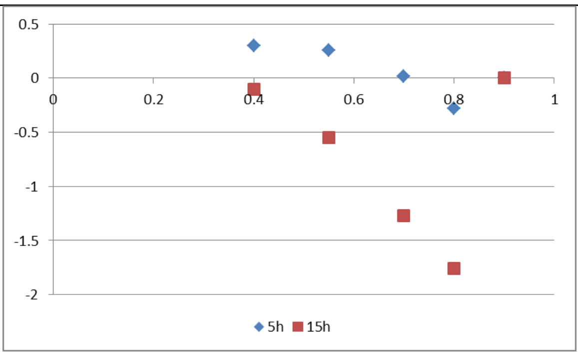


Y: Eroded Volume %

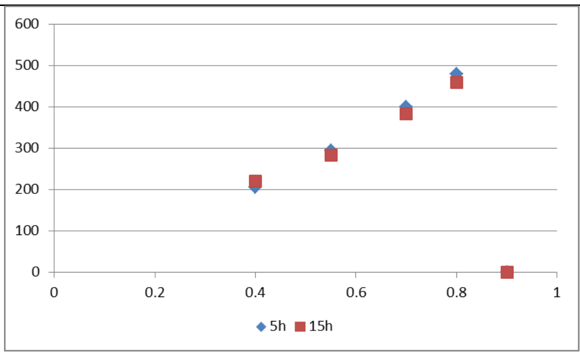


X: Gamma

Y: BSS

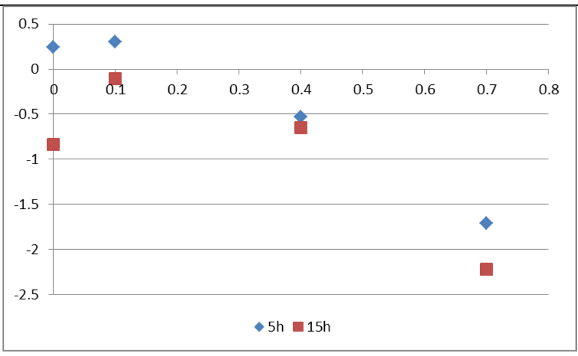


Y: Eroded Volume %

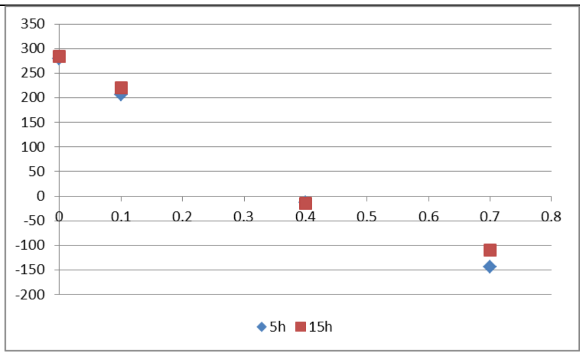


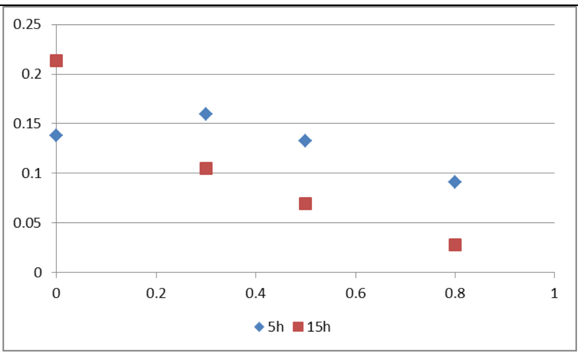
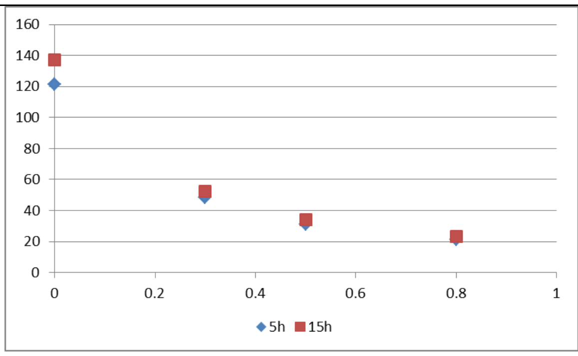
X: Facua

Y: BSS



Y: Eroded Volume %



X: Fw	
Y: BSS	Y: Eroded Volume %
	

Appendix D-3: Water Level Accuracy Model Runs

Run	Start Time (h)	End Time (h)
1	0.00	3.10
2	3.10	6.20
3	6.20	9.30
4	12.40	15.40
5	31.00	34.10
6	37.20	40.30
7	0.00	6.20
8	3.10	9.30
9	6.00	12.40
10	9.30	15.50
11	24.80	31.00
12	31.00	37.20
13	0.00	9.30
14	3.10	12.40
15	15.50	24.80
16	24.80	34.10
17	0.00	12.40
18	3.10	15.50
19	12.40	24.80
20	24.80	37.20
21	0.00	24.80
22	15.50	40.30
23	0.00	40.30

Appendix D-4: Water Level Accuracy Run 23 Model Configuration/Parameter Setups

****

*   SBEACH model configuration file: Run 23.CFG   *

****

A--------------------------- MODEL SETUP ------------------------------A

A.1 RUN TITLE: TITLE

Run 23: Varying Water Levels from 0h - 40.3h

A.2 INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS

1

A.3 TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY

RELATIVE TO INITIAL PROFILE: NDX, XSTART

65   -20.1168

A.4 GRID TYPE (CONSTANT=0, VARIABLE=1): IDX

0

A.5 COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6 CONSTANT GRID CELL WIDTH: DXC

1.2192

A.7 COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8 NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID

2

A.9 GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD

TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)

2, 99 1, 899

A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT

12090   0.2

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR

5

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)

930 1860 2790 3720 7740

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP

0

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH WILL BE DETERMINED): ELV1, ELV2, ELV3

1.00 0.5 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED EDP1, EDP2, EDP3, REFELV

1.00 0.5 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K

1.15E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS

0.00100

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM

0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC

26

B---------------------- WAVES/WATER ELEVATION/WIND ----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE

1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE

0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T

1.34 7.87

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV

60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG

0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN

0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG

0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS

0

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND

0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC

7878 20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV

1

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV

0

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV

1.00

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND

0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND

0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND

0.00

C------------------------------ BEACH ----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN

1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,

LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,

END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,

XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS

0.15

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50

0.4

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX

30.00

D------------------------------ BEACH FILL ---------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL

0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE

TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START

AND END OF BEACH FILL: NFILL

0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE

INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E--------------------------- SEAWALL/REVETMENT ----------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL

0

E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.

E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL

0.00

E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL

0

E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.

E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION

AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES

FAILURE: PEFAIL, WEFAIL,HFAIL

0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F

----------------------------------- END ------------------------------------

%%% XBeach parameter settings input file %%%

%%% date: 30-Aug-2016 12:00 %%%

%%% function: xb_write_params %%%

%%% Calibration parameters %%

wetslp = 1
gamma = 0.4
facua = 0.2
fw = 0.08

%%% Grid parameters %%

%xbeach/delft3d
gridform = xbeach

depfile = DepSeaLevel.dep
posdwn = -1
alfa = 0
dx = 1.2192
dy = 0
nx = 65
ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90
thetamax = +90
dtheta = 10
thetanaut = 0

%%% Model time %%%

tstart = 0
tstop = 145080
tintg = 60
tintp = 60

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rho = 1025
g = 9.81

D50 = 0.0004
rhos = 2650
por = 0.3

%%% Flow boundary conditions %%

front = abs_1d
back = abs_1d
left = 0
right = 0

%%% Tide boundary conditions %%

tideloc = 1
zs0file = tide.txt

%%% Wave boundary Conditions %%

instat = 0
Hrms = 1.34
Trep = 7.87

%%% Morphology Conditions %%

morfac = 1
morstart = 0

%%% Output variables %%

outputformat = netcdf

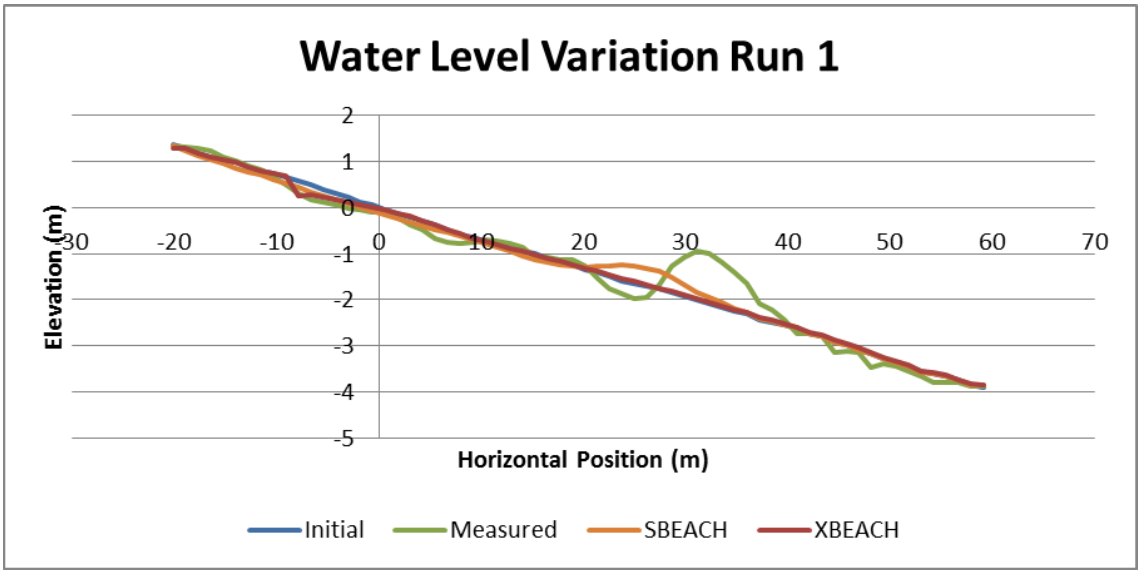
nglobalvar = 6
zb
zb0
zs
H
hh
Qb

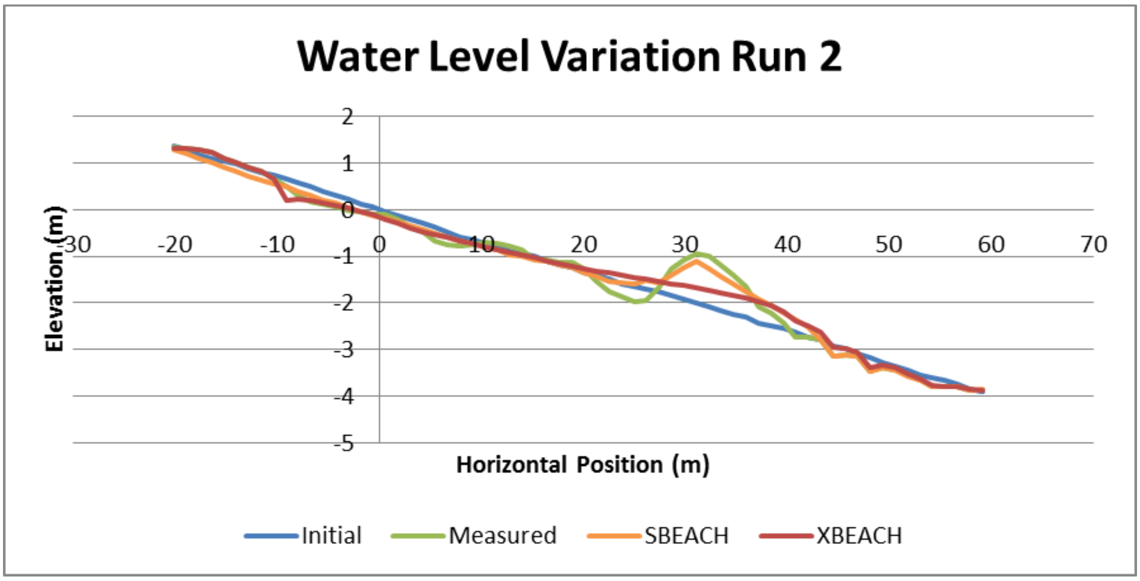
nmeanvar = 3
H
hh
zs

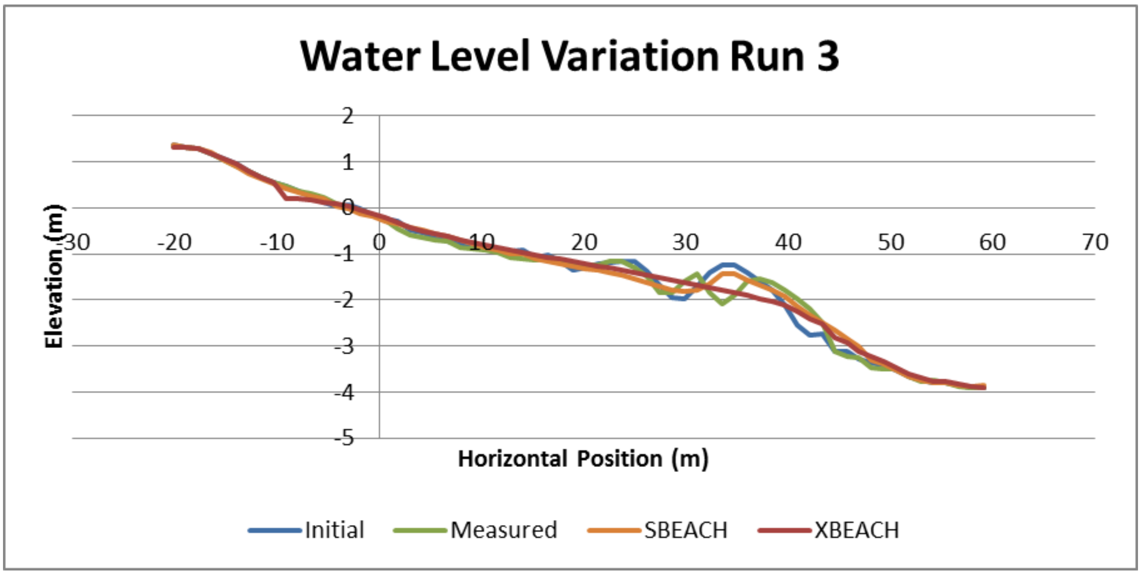
Appendix D-5: Water Level Accuracy Comparison Parameters

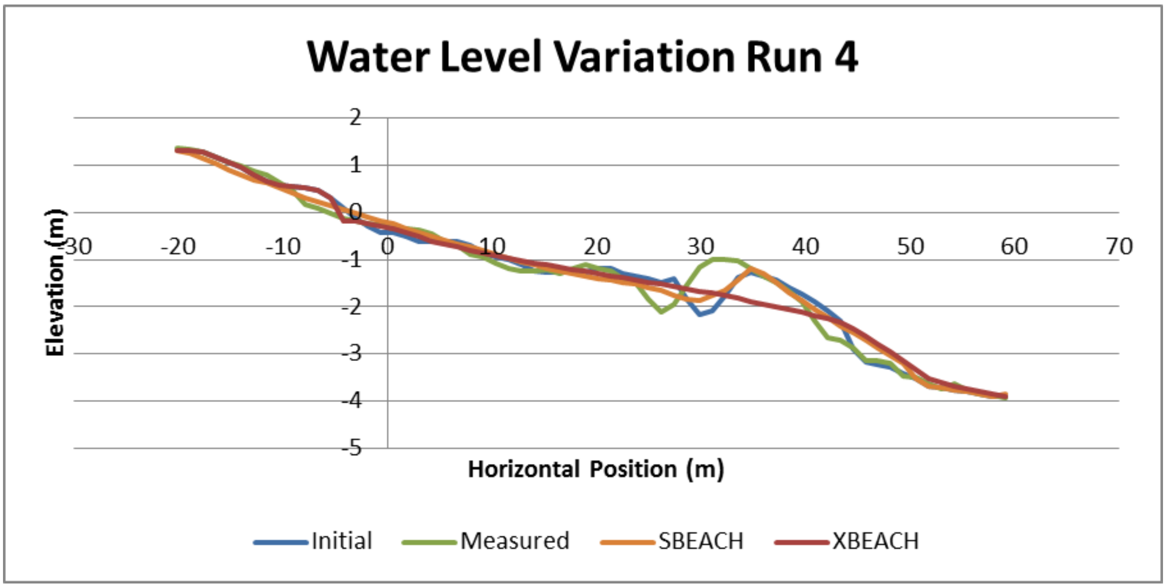
Run	Eroded Volume of Sediment Above Water Level (m^3/m)			Shoreline Recession (m)			BSS		
	SB	XB	DR	SB	XB	DR	SB	XB	DR
1	1.8	1.2	-	1.7	0.3	-	0.1	0.1	-
2	0.5	0.4	-	-1.0	-1.0	-	0.5	0.5	-
3	-0.1	0.6	-	1.3	0.4	-	0.3	0.4	-
4	1.1	0.2	-	-0.3	1.0	-	0.3	-0.1	-
5	-0.6	0.4	-	-0.7	1.5	-	0.3	0.4	-
6	0.9	0.3	-	0.7	0.7	-	0.2	-0.1	-
7	2.2	1.9	-	2.7	1.7	-	0.2	0.2	-
8	0.4	0.6	-	-0.7	-0.5	-	0.7	0.6	-
9	-0.8	0.8	-	1.7	1.0	-	0.4	-0.5	-
10	0.6	0.0	-	0.5	0.0	-	0.0	-0.7	-
11	-1.5	-0.3	-	1.4	1.0	-	-0.8	-2.1	-
12	-1.6	0.4	-	0.2	1.6	-	0.2	-0.6	-
13	2.2	2.5	-	3.2	3.7	-	0.5	0.1	-
14	-0.3	0.8	-	-0.4	1.0	-	0.8	0.4	-
15	-0.3	0.5	-	-1.3	-0.4	-	0.6	0.4	-
16	0.1	0.3	-	1.7	-0.2	-	-0.8	-1.0	-
17	2.1	2.7	-	3.5	4.4	-	0.7	0.1	-
18	0.8	0.9	-	0.1	1.6	-	-0.4	-1.6	-
19	0.4	-0.2	-	0.1	1.0	-	-1.0	-2.7	-
20	-1.0	0.3	-	1.9	1.0	-	-3.1	-5.0	-
21	1.0	3.6	-	4.9	6.9	-	0.7	0.1	-
22	-2.1	0.8	-	-0.8	1.8	-	-0.9	-1.3	-
23	1.3	3.9	-	5.7	8.0	-	0.4	0.2	-

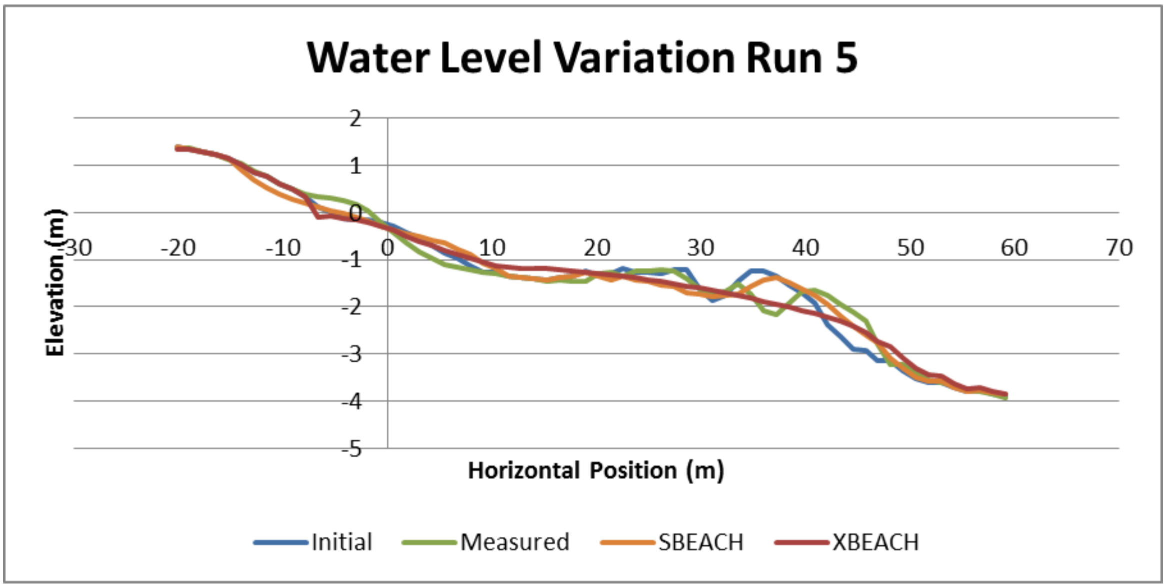
Appendix D-6: Water Level Variation Model Accuracy Runs Output

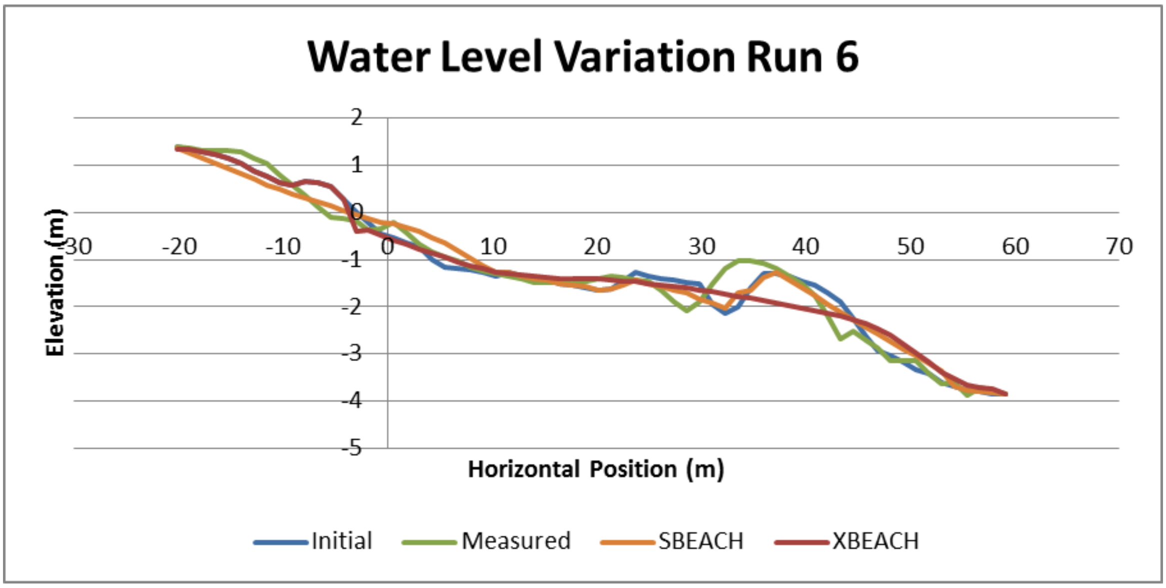


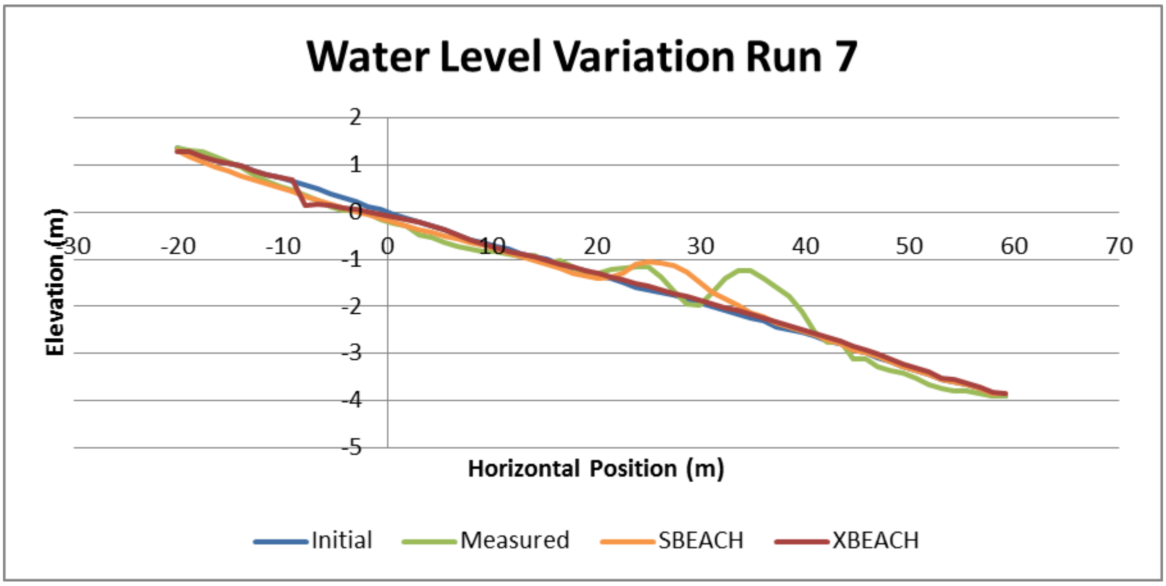


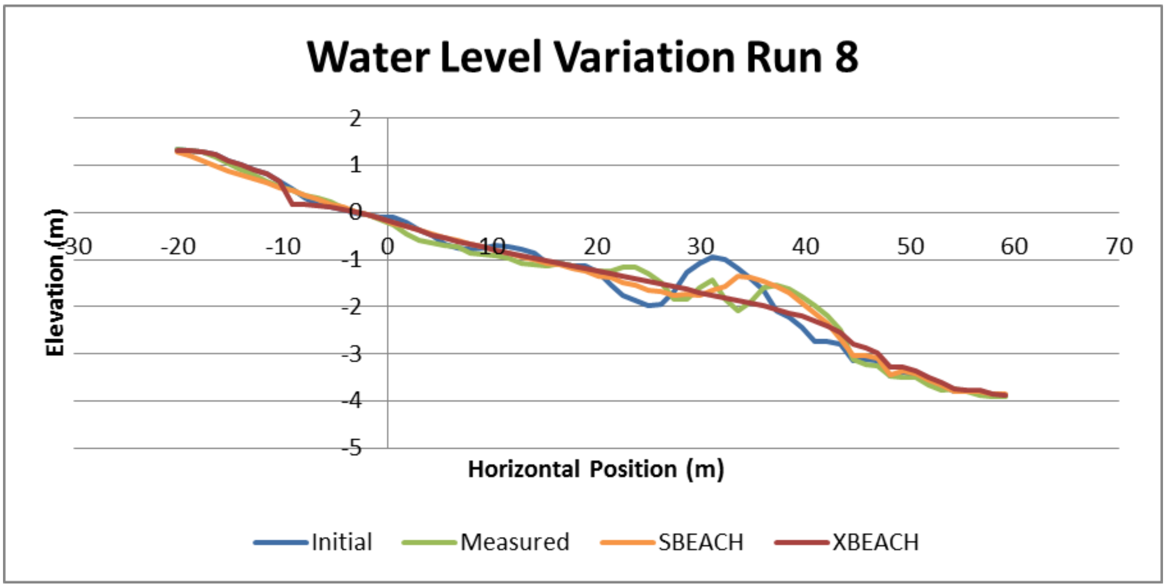


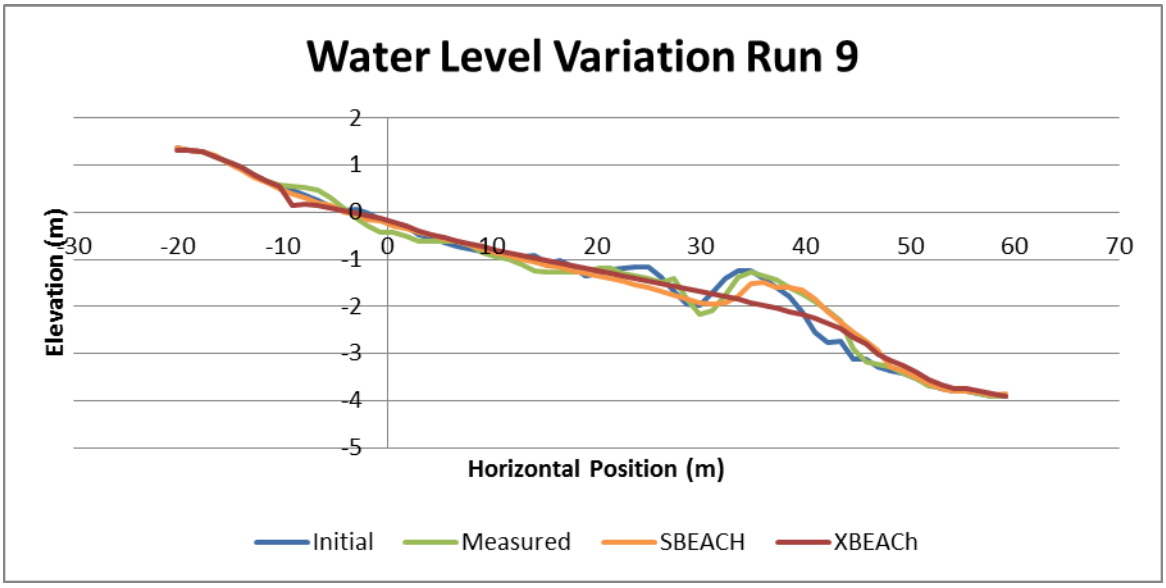

Water Level Variation Run 4
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

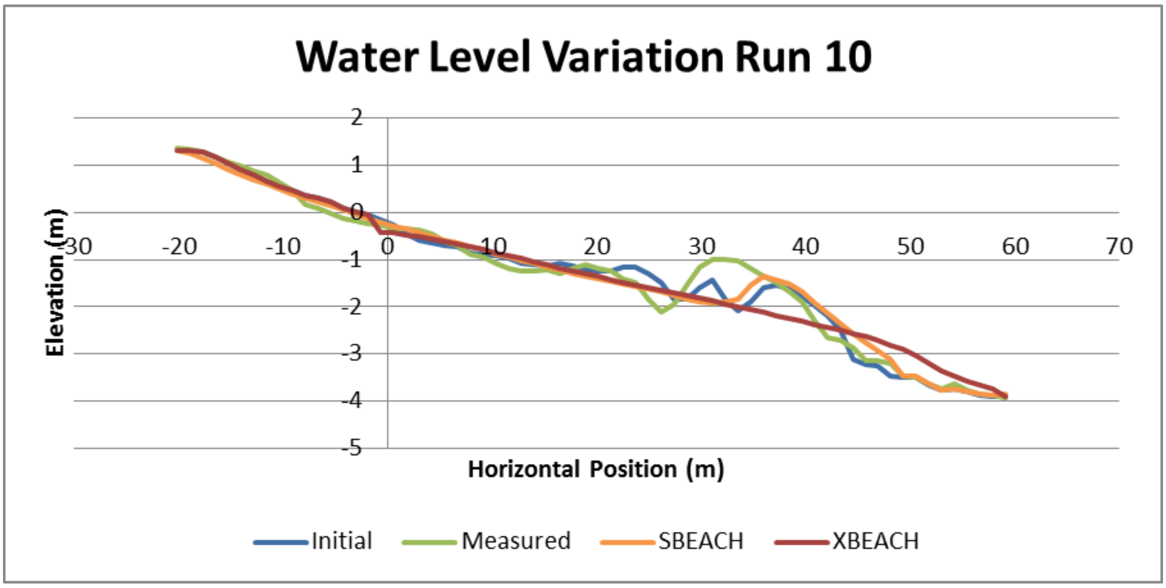

Water Level Variation Run 5
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

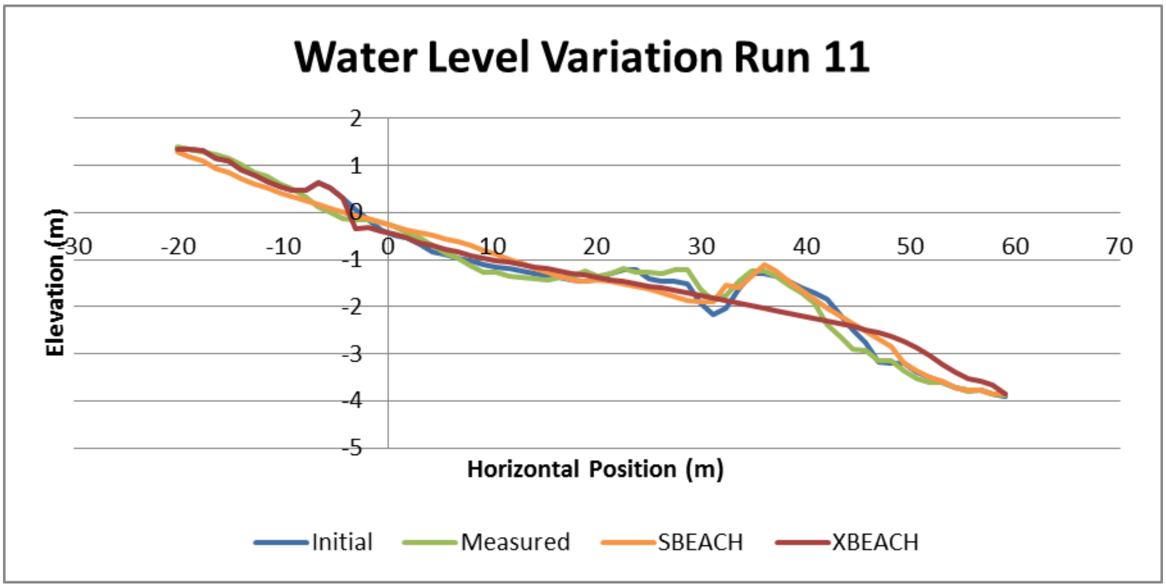

Water Level Variation Run 6
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

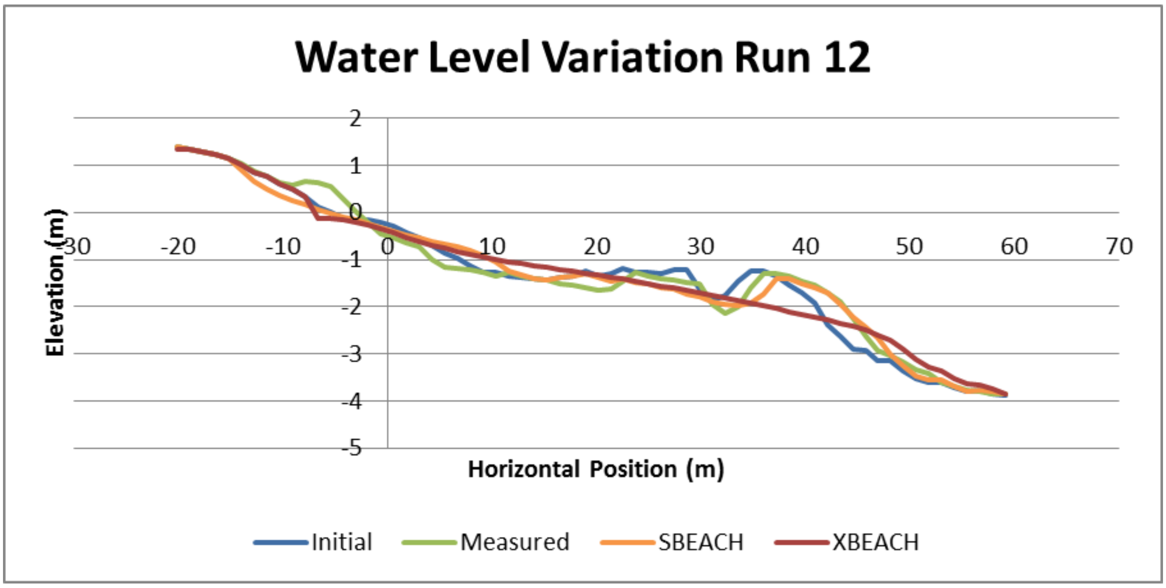

Water Level Variation Run 7
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH

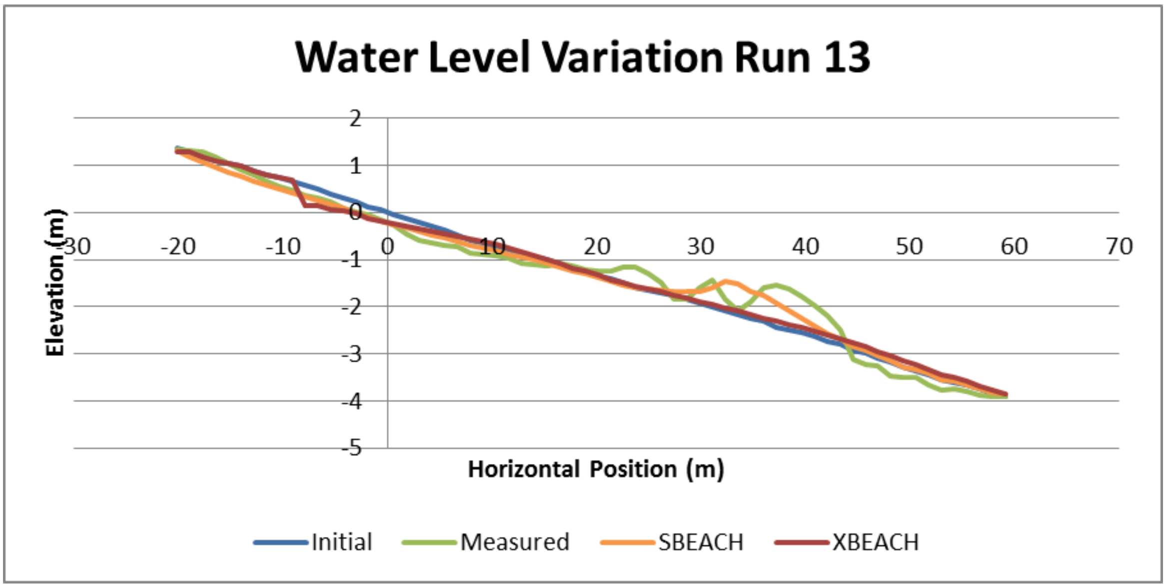

Water Level Variation Run 8
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH

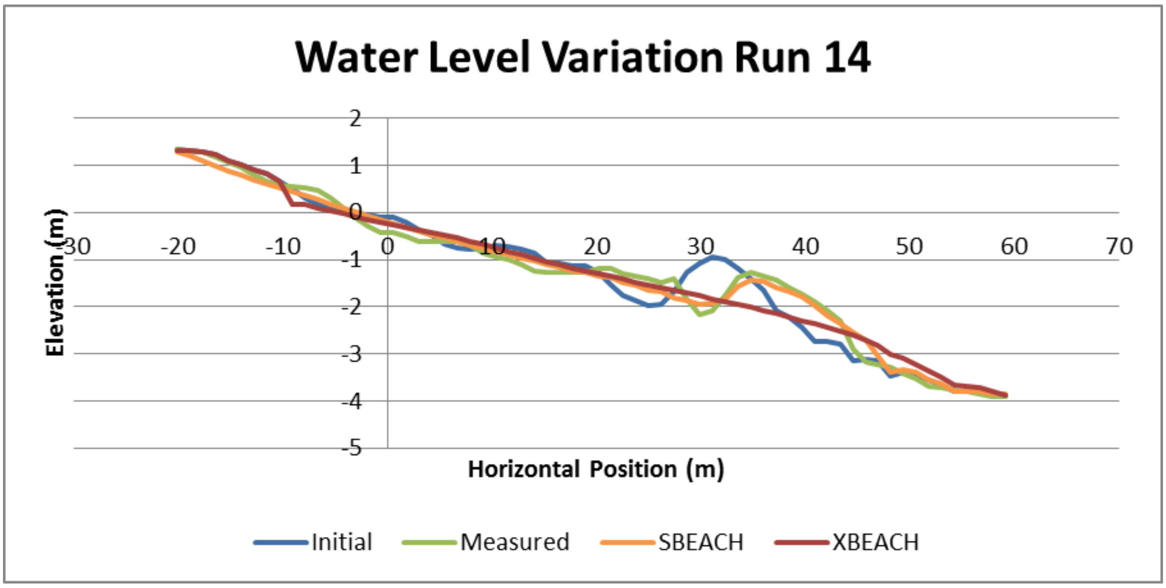

Water Level Variation Run 9
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACh

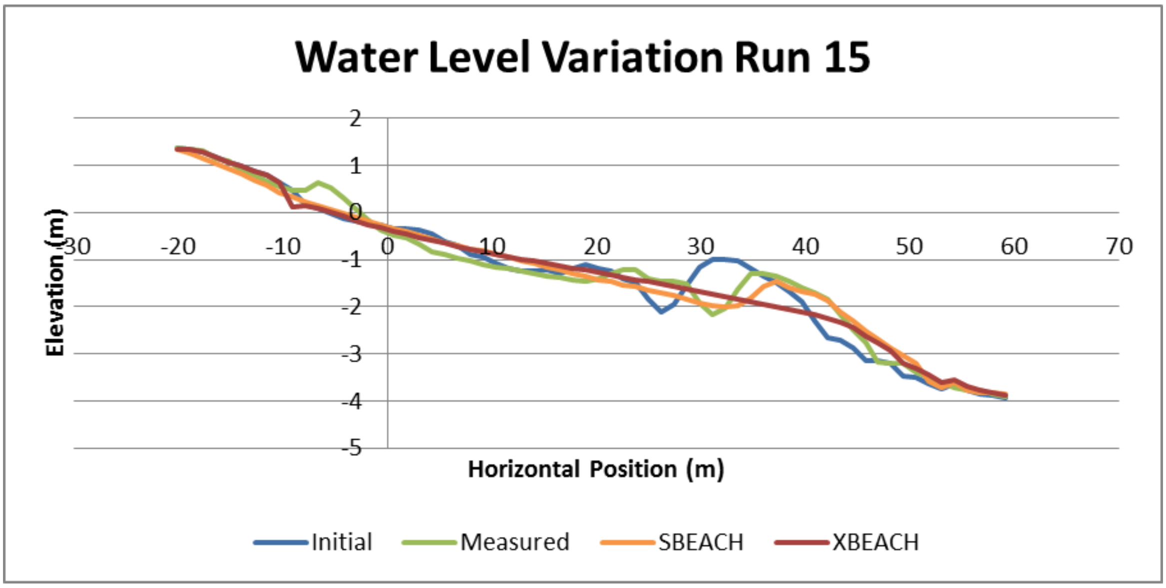

Water Level Variation Run 10
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

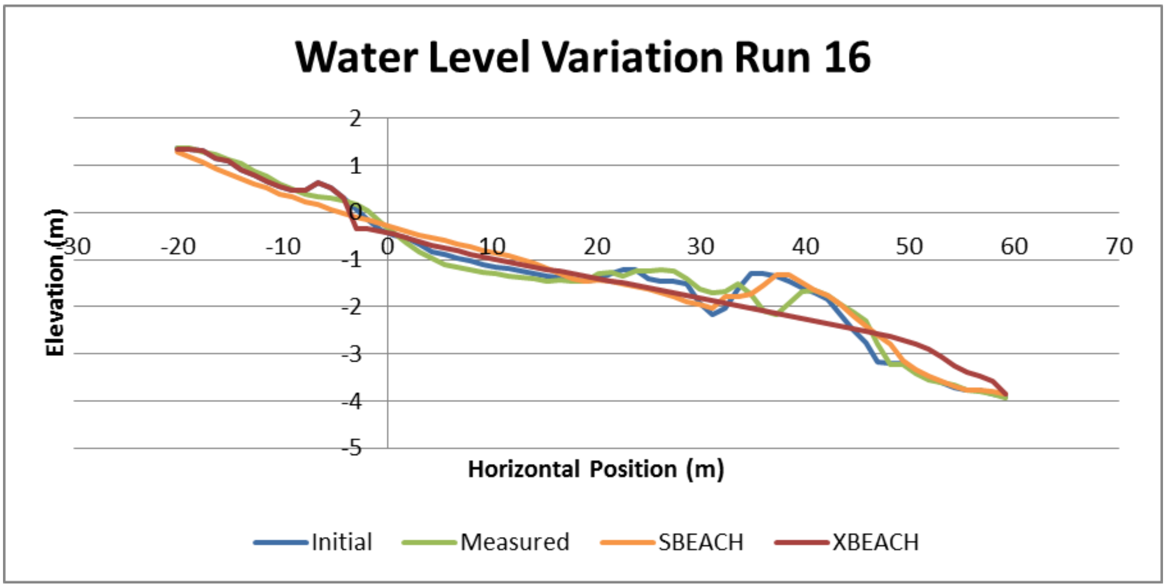

Water Level Variation Run 11
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

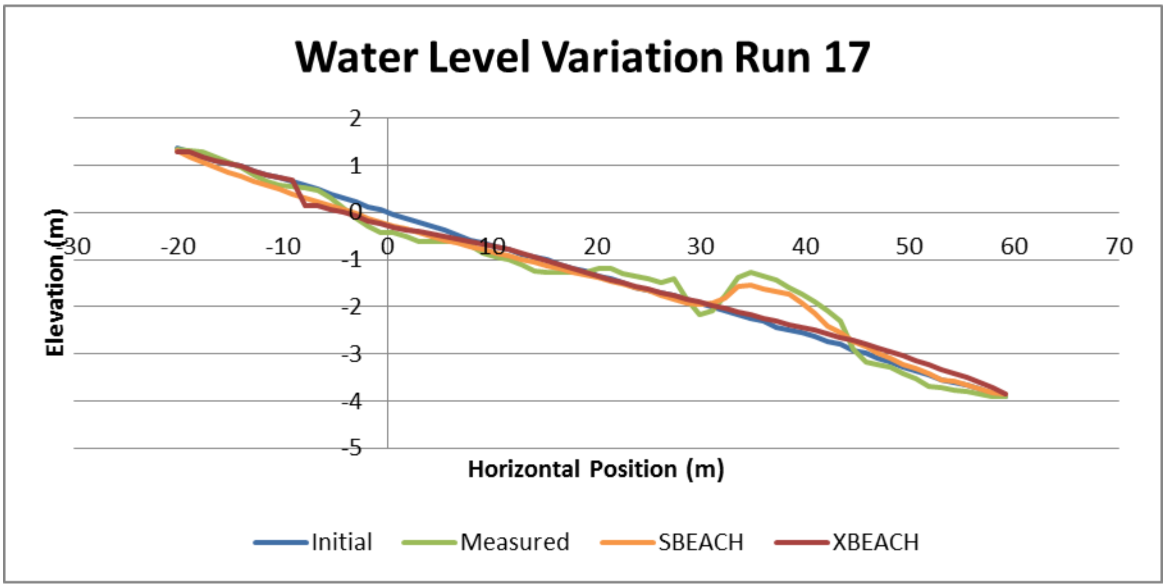

Water Level Variation Run 12
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

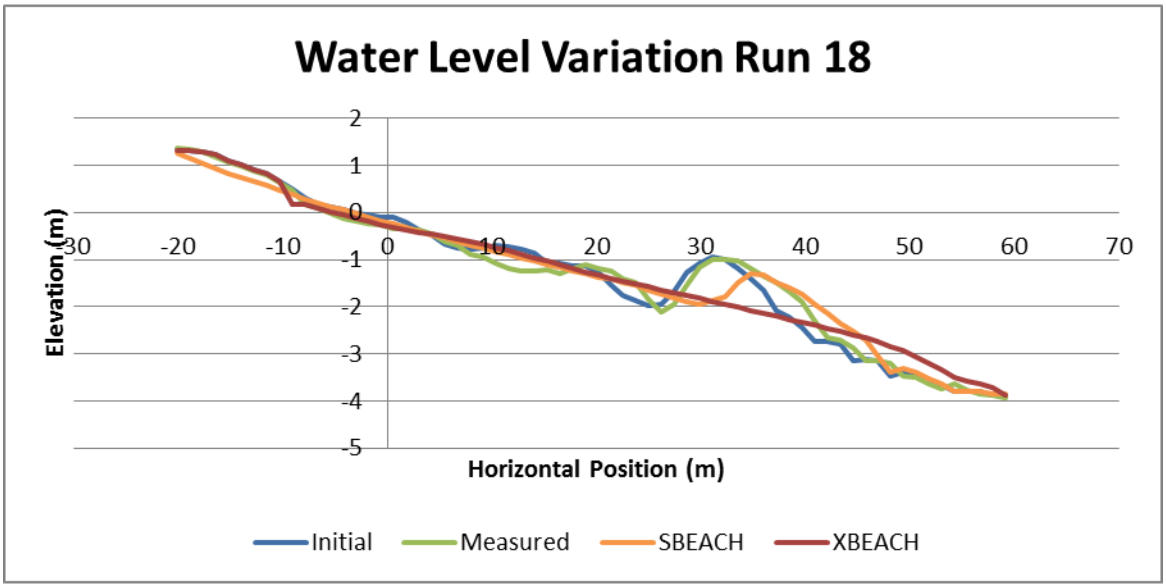

Water Level Variation Run 13
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

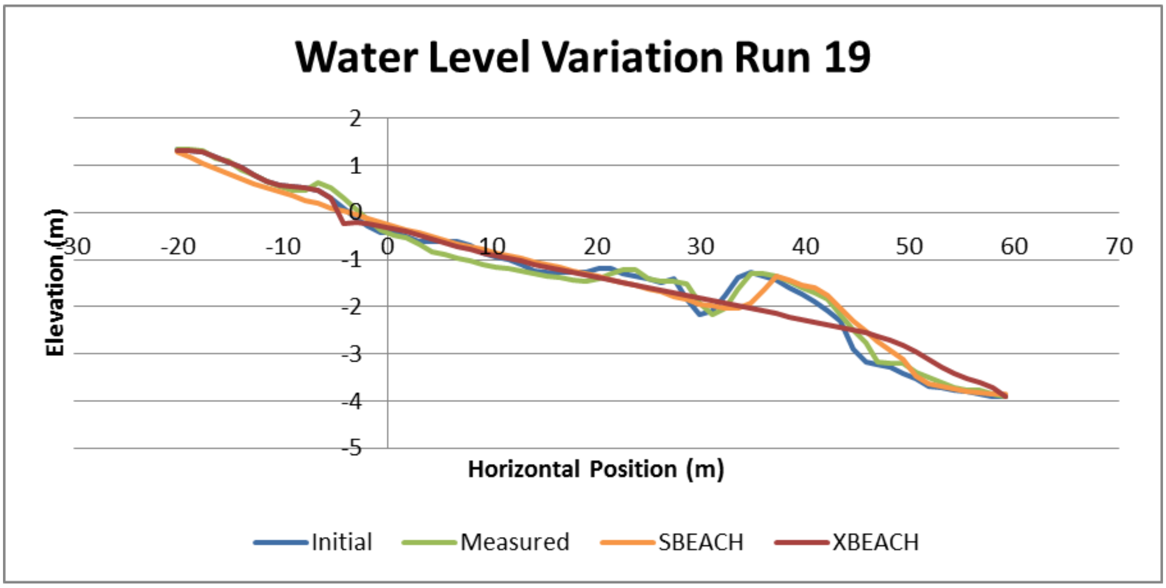

Water Level Variation Run 14
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

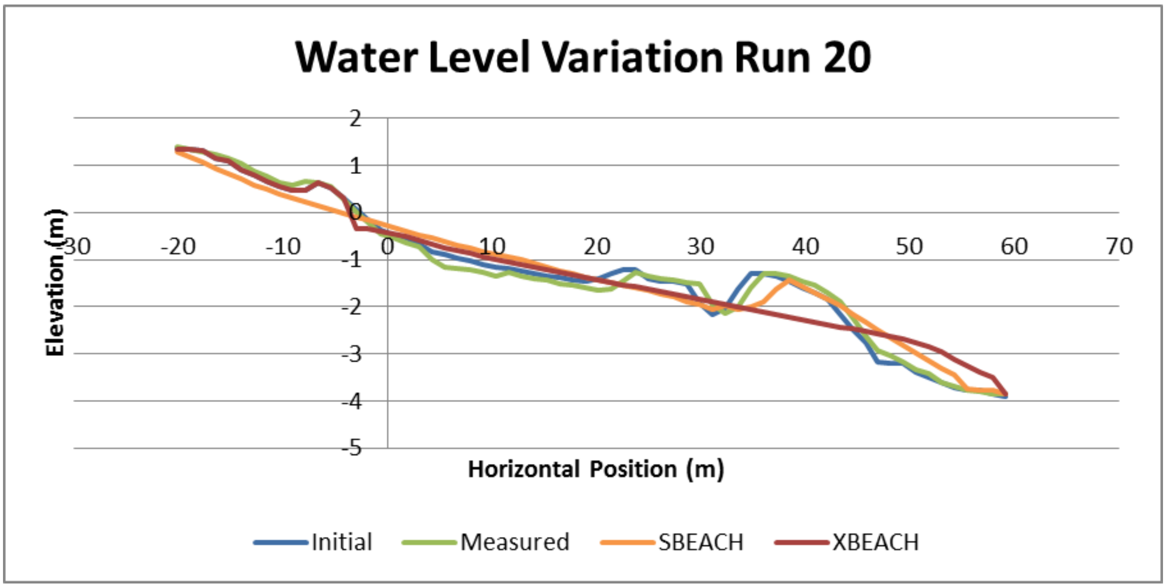

Water Level Variation Run 15
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

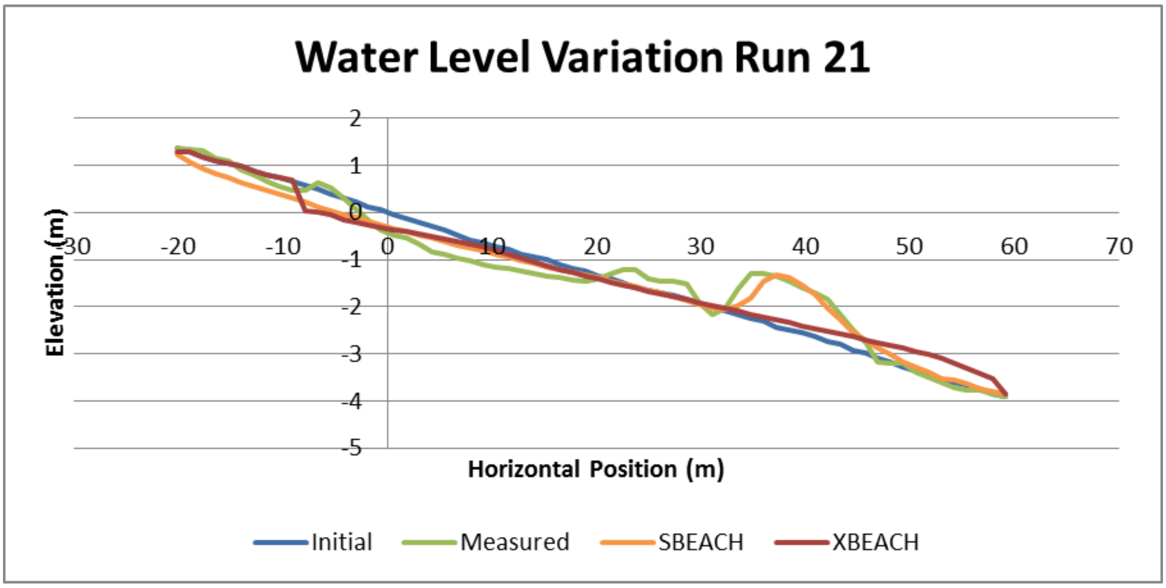

Water Level Variation Run 16
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH

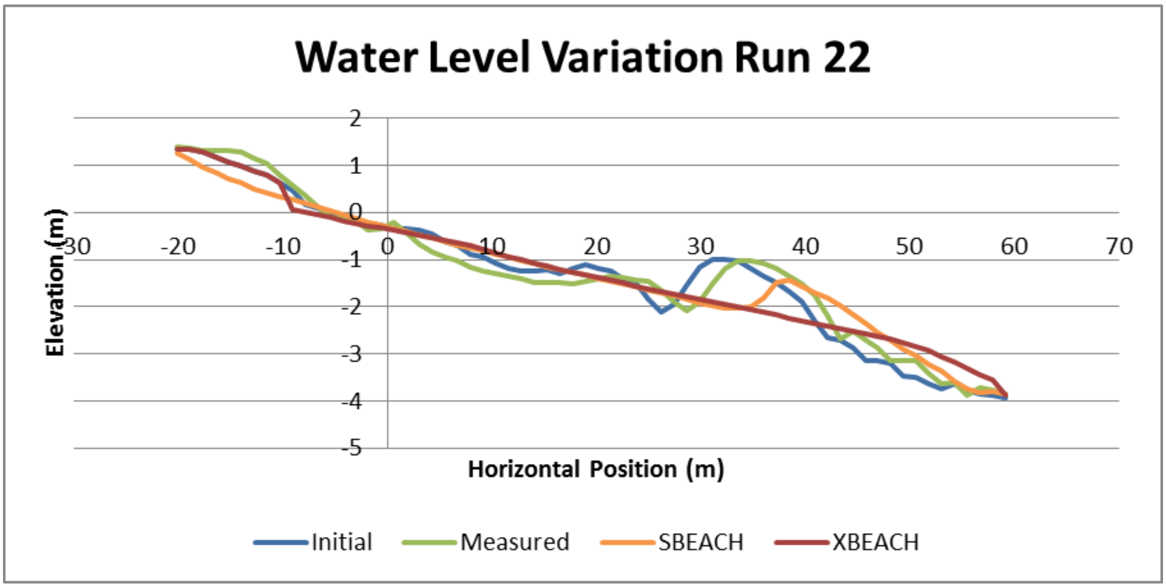

Water Level Variation Run 17
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH

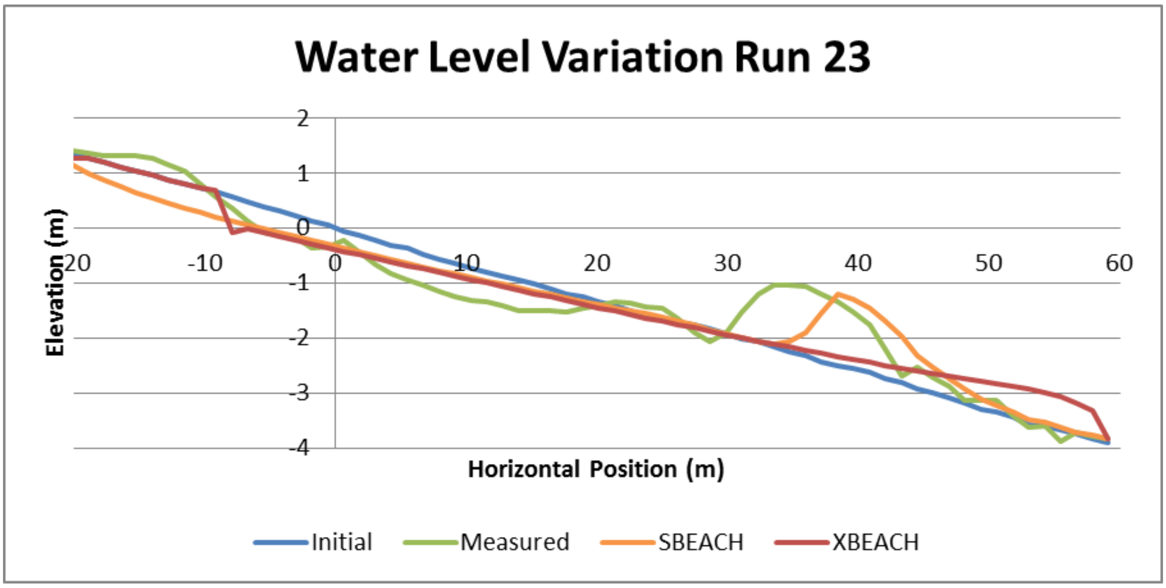

Water Level Variation Run 18
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH


Water Level Variation Run 19
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Water Level Variation Run 20
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Water Level Variation Run 21
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Water Level Variation Run 22
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-20
-10
0
10
20
30
40
50
60
70
Initial
Measured
SBEACH
XBEACH

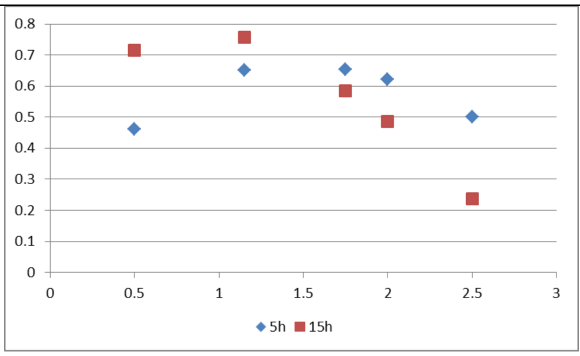
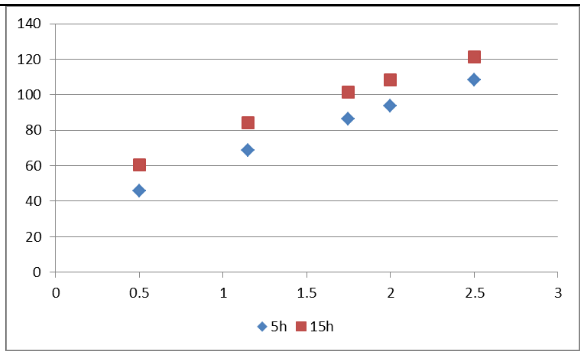

Water Level Variation Run 23
Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-20
-10
0
10
20
30
40
50
60
Initial
Measured
SBEACH
XBEACH

APPENDIX E: STORM DURATION ACCURACY

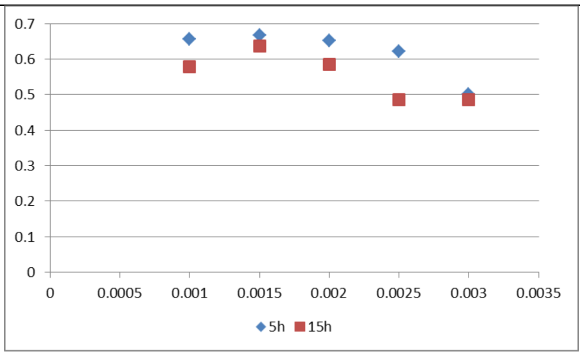
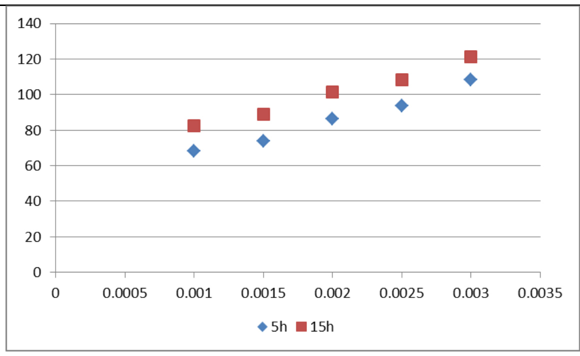
Appendix E-1: SBEACH Storm Duration Accuracy Calibration

Case 300

X: TRANSPORT RATE COEFFICIENT (m^4/N)

Y: BSS	Y: Eroded Volume %
	

X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

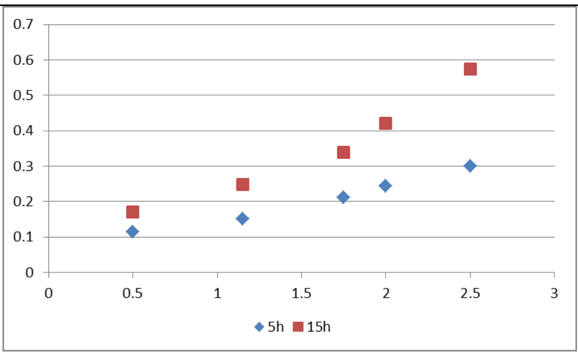
Y: BSS	Y: Eroded Volume %
	

*Other parameters were also calibrated, but the file was corrupted

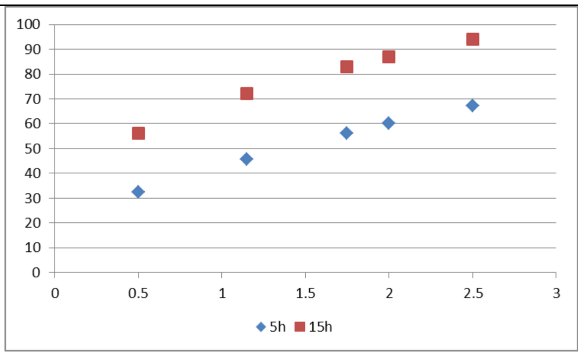
Case 400

X: TRANSPORT RATE COEFFICIENT (m^4/N)

Y: BSS

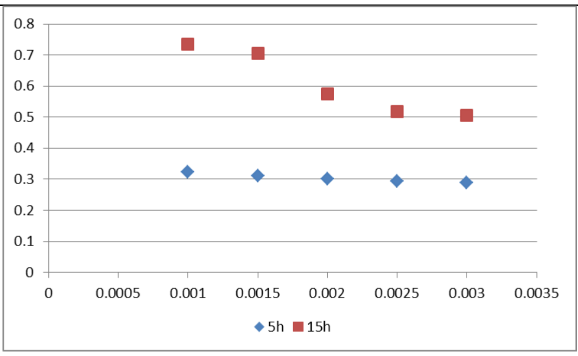


Y: Eroded Volume %

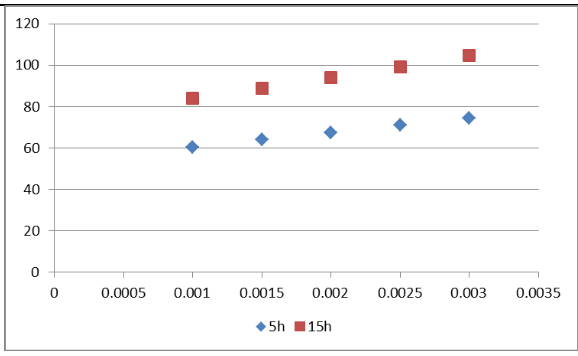


X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS

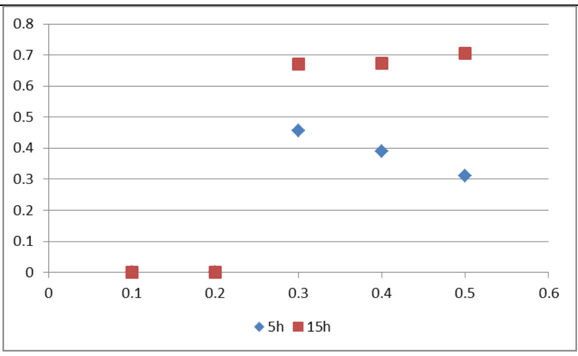


Y: Eroded Volume %

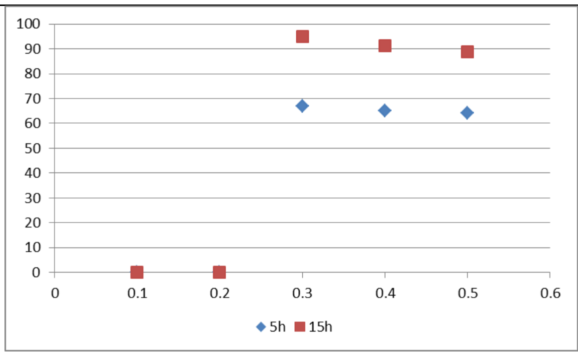


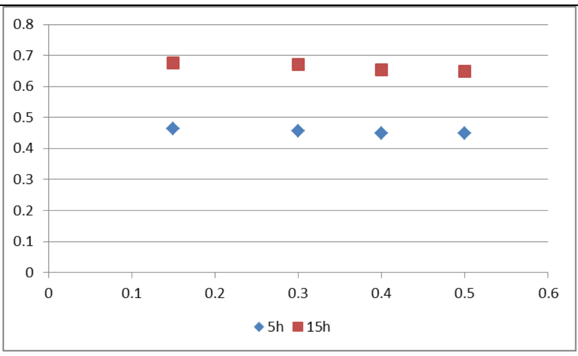
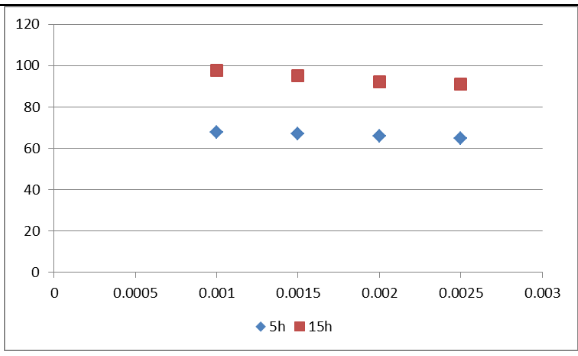
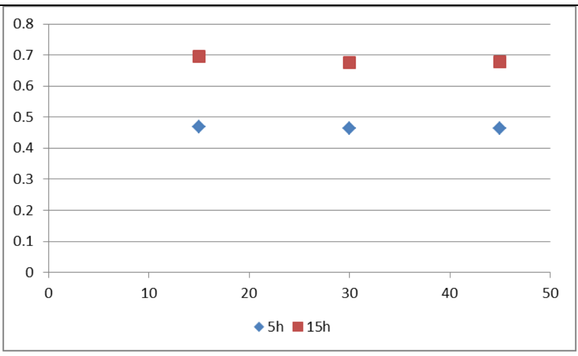
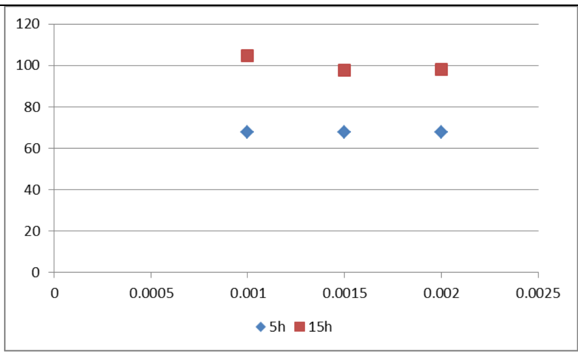
X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

Y: BSS



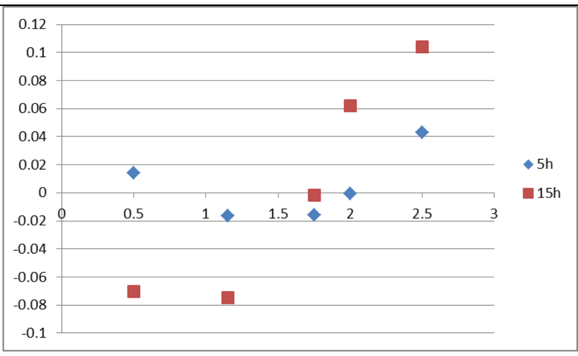
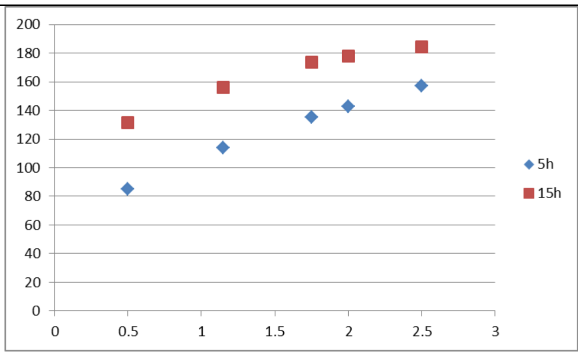
Y: Eroded Volume %



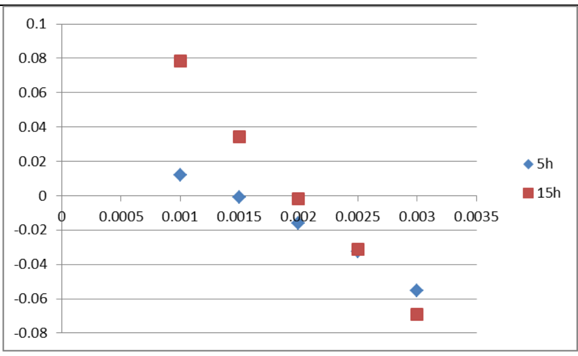
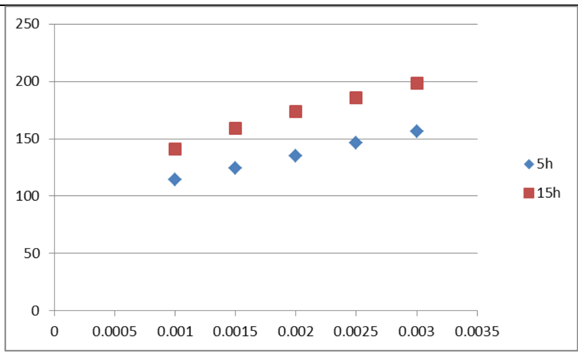
X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)	
Y: BSS	**Y: Eroded Volume %**
	
X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES	
Y: BSS	**Y: Eroded Volume %**
	

Case 500

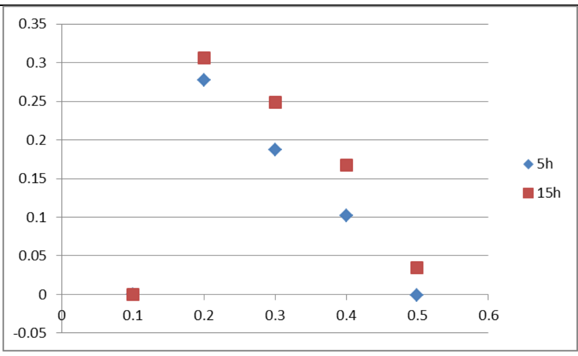
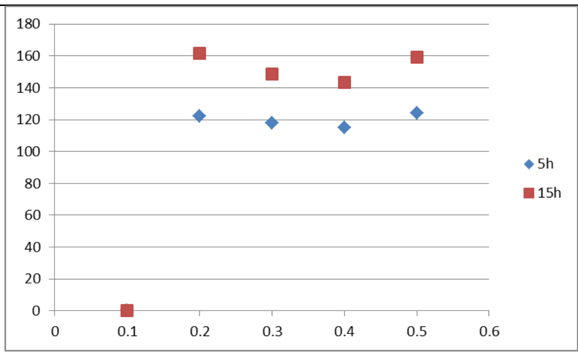
X: TRANSPORT RATE COEFFICIENT (m^4/N)

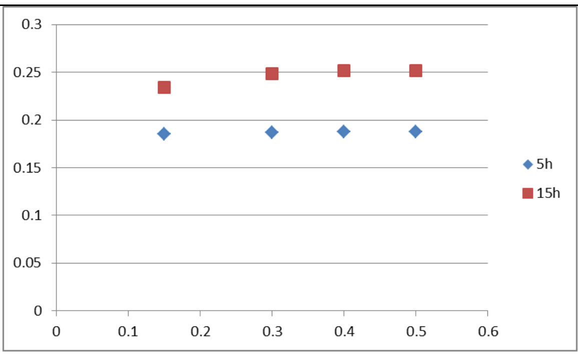
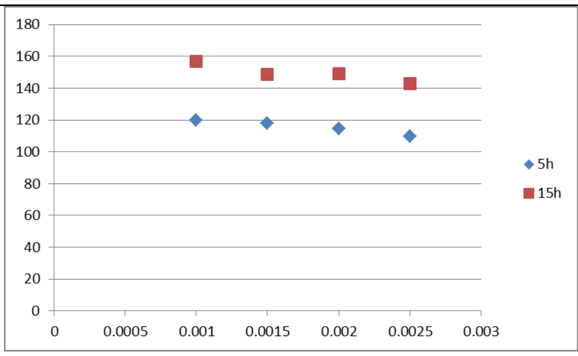
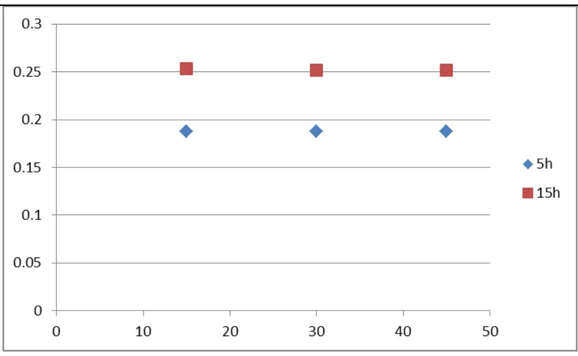
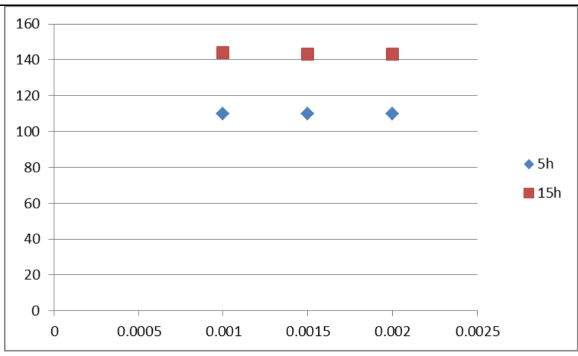
Y: BSS	Y: Eroded Volume %
	

X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS	Y: Eroded Volume %
	

X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

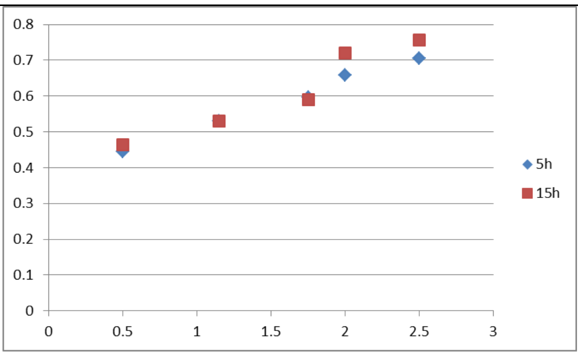
Y: BSS	Y: Eroded Volume %
	

<table>
<tr><th colspan="2">X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

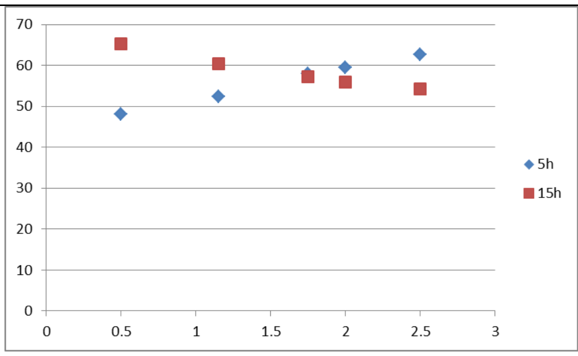
Case 401

X: TRANSPORT RATE COEFFICIENT (m^4/N)

Y: BSS

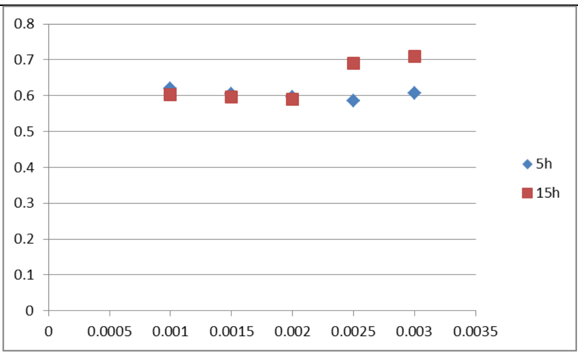


Y: Eroded Volume %

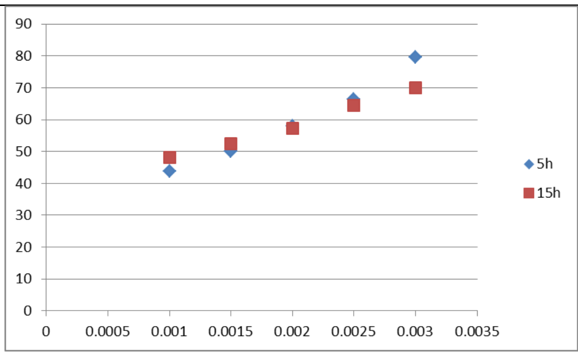


X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS

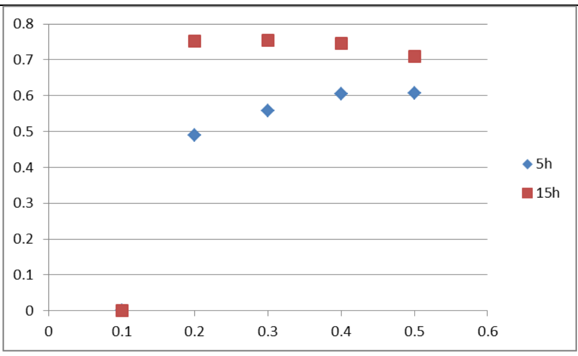


Y: Eroded Volume %

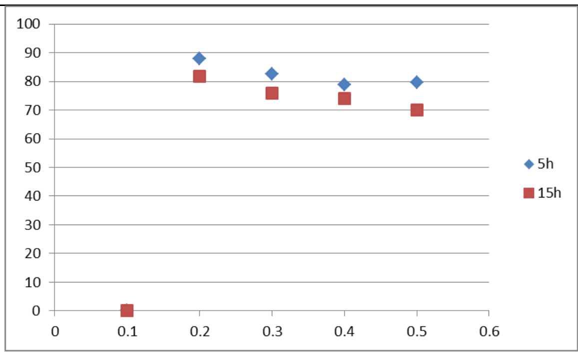


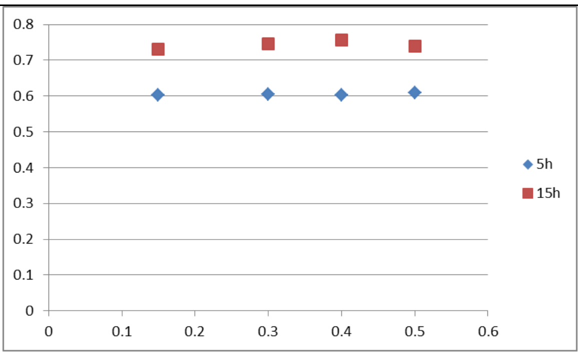
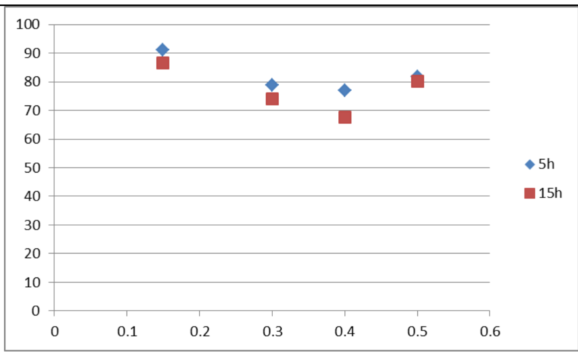
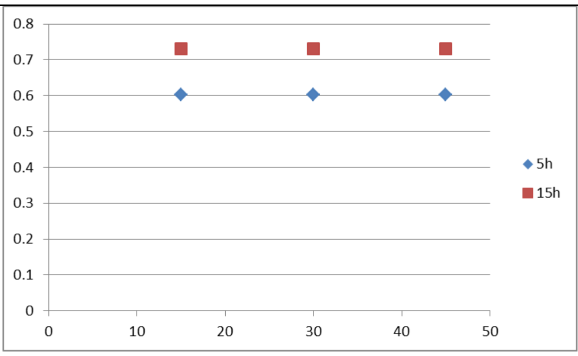
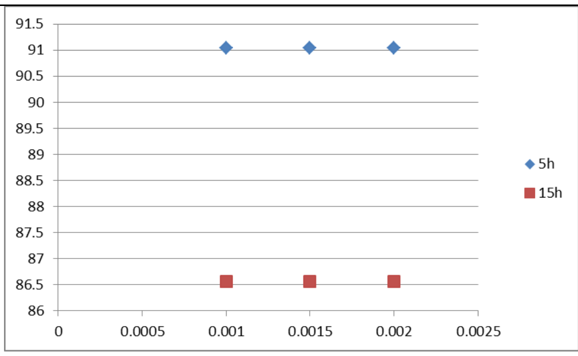
X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

Y: BSS



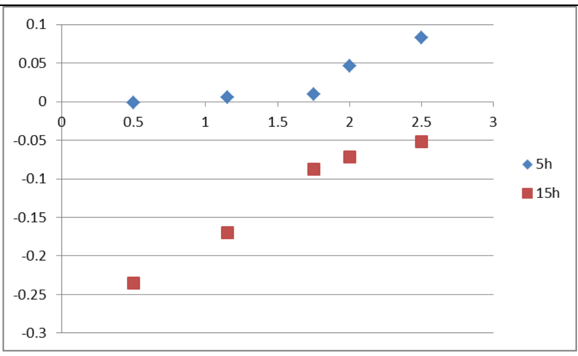
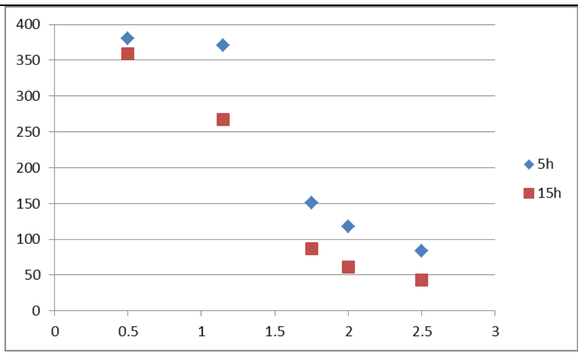
Y: Eroded Volume %



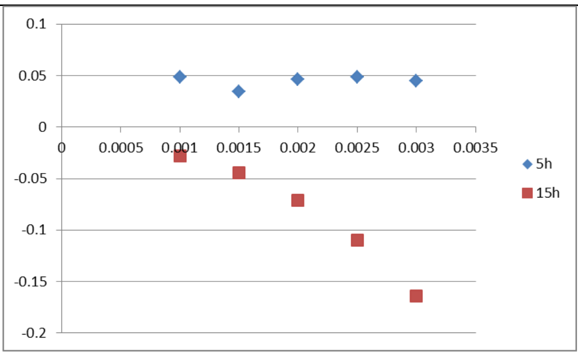
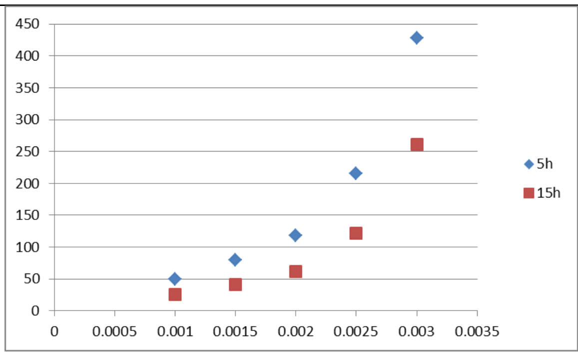
X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)	
Y: BSS	Y: Eroded Volume %
	
X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES	
Y: BSS	Y: Eroded Volume %
	

Case 501

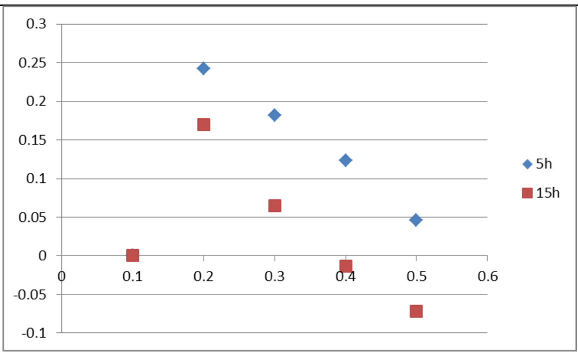
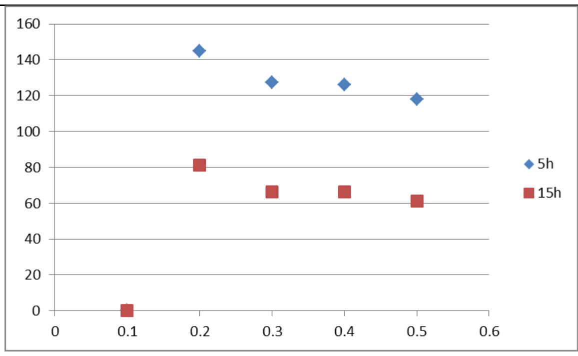
X: TRANSPORT RATE COEFFICIENT (m^4/N)

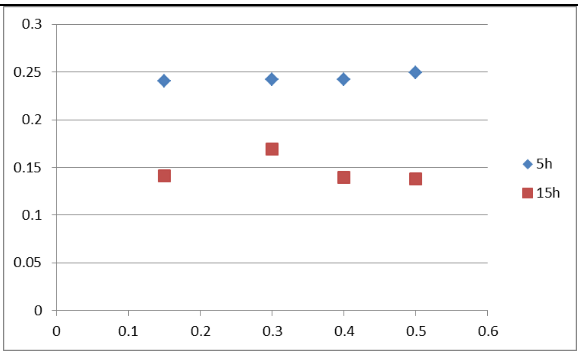
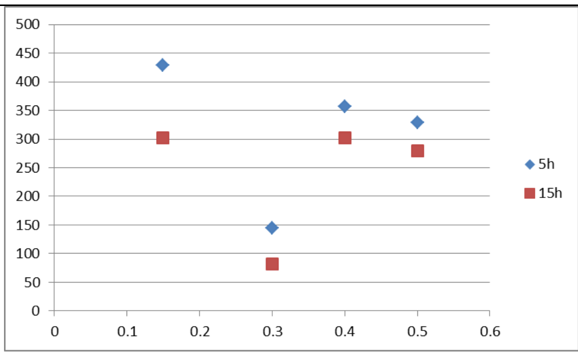
Y: BSS	Y: Eroded Volume %
	

X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS	Y: Eroded Volume %
	

X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

Y: BSS	Y: Eroded Volume %
	

<table>
<tr><th colspan="2">X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
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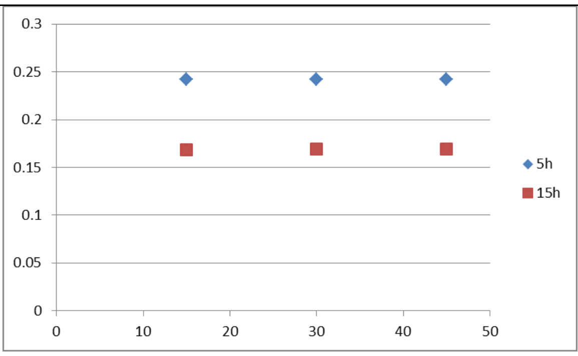
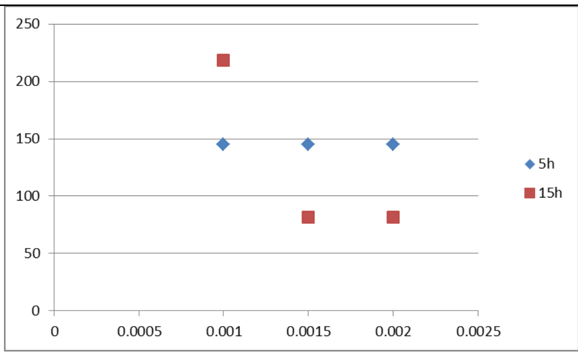
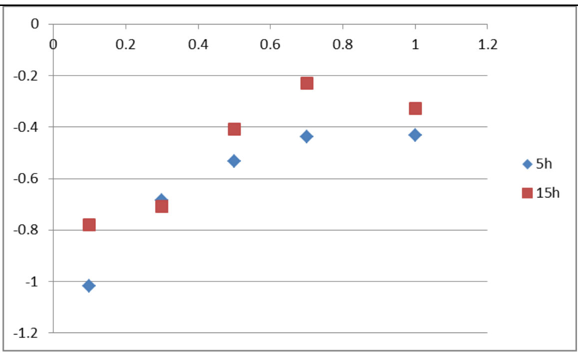
<tr><th colspan="2">X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Appendix E-2: SBEACH Storm Duration Accuracy Calibration

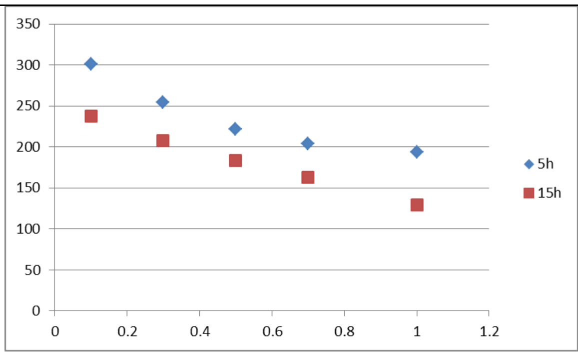
Case 300

X: wetslp

Y: BSS

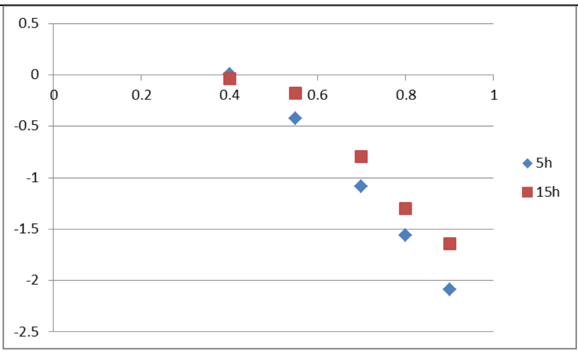


Y: Eroded Volume %

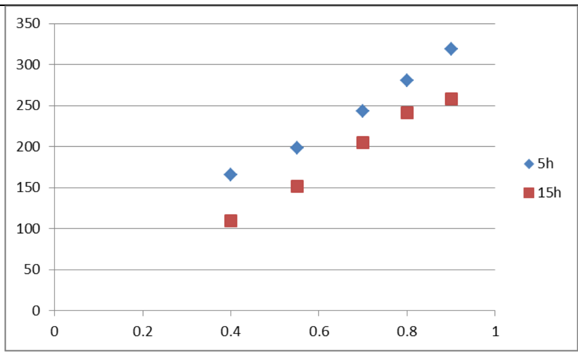


X: Gamma

Y: BSS

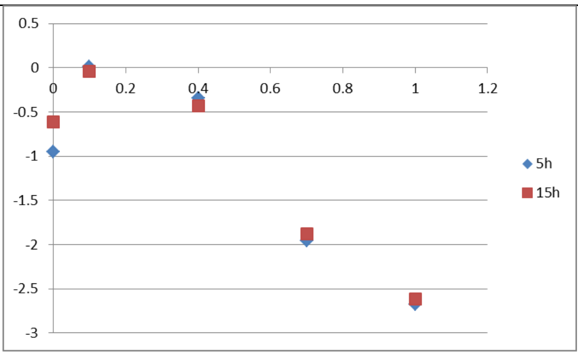


Y: Eroded Volume %

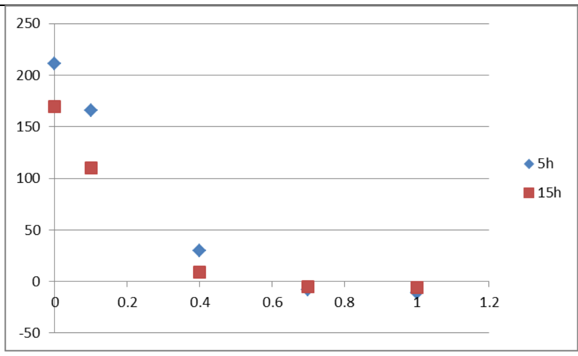


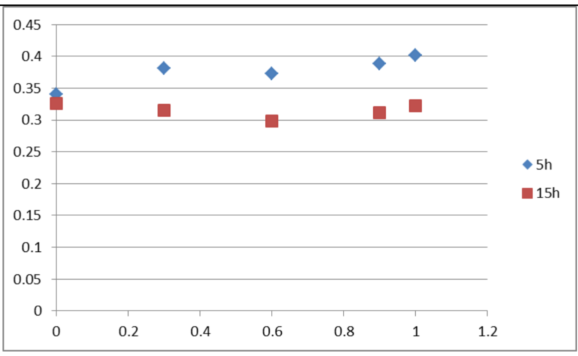
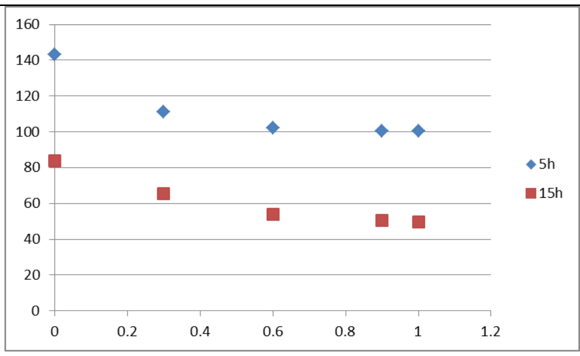
X: Facua

Y: BSS

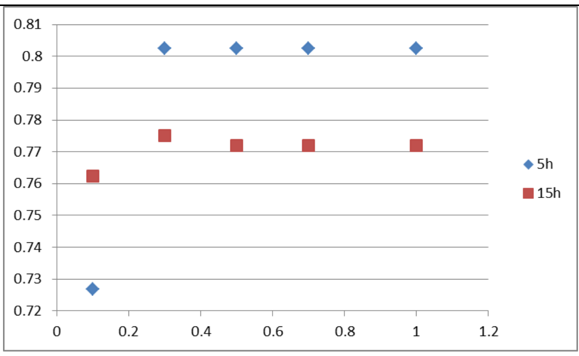
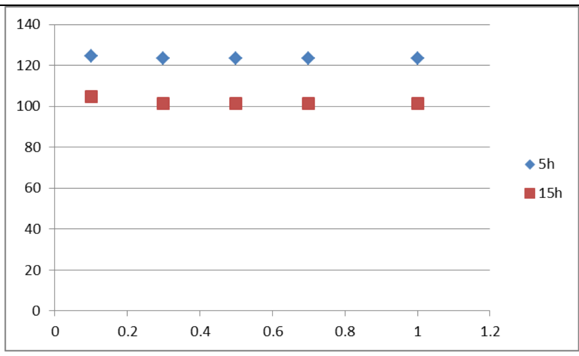
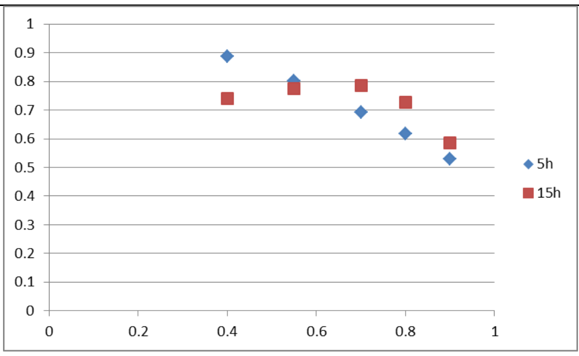
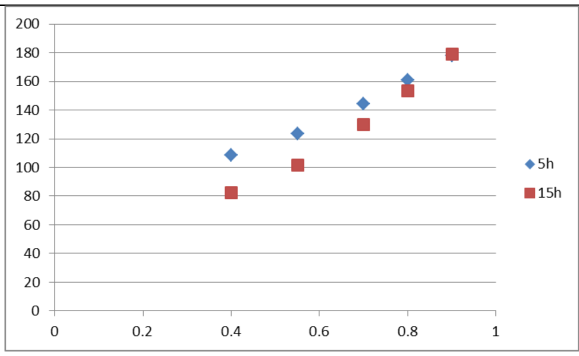


Y: Eroded Volume %



<table>
<tr><th colspan="2">X: Fw</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Case 400

<table>
<tr><th colspan="2">X: wetslp</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">X: Gamma</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
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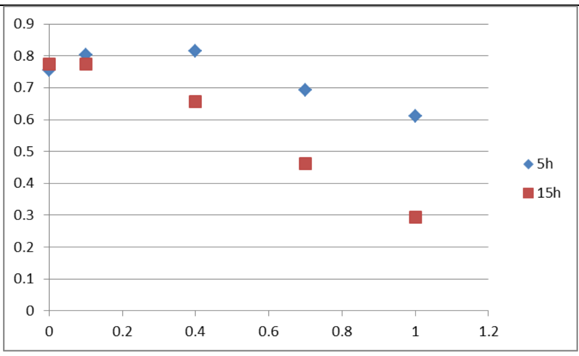
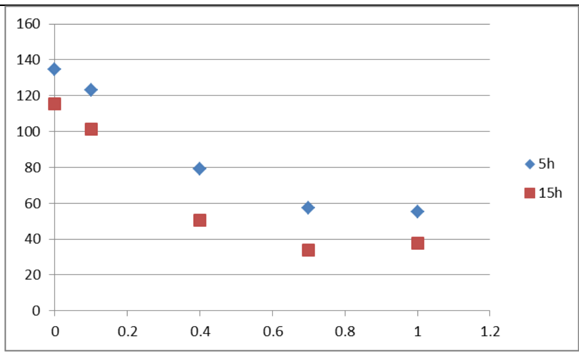
<tr><th colspan="2">X: Facua</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
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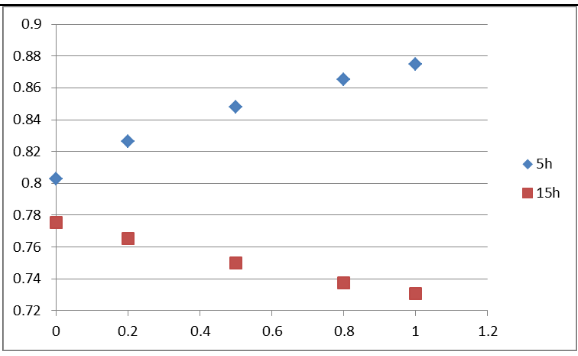
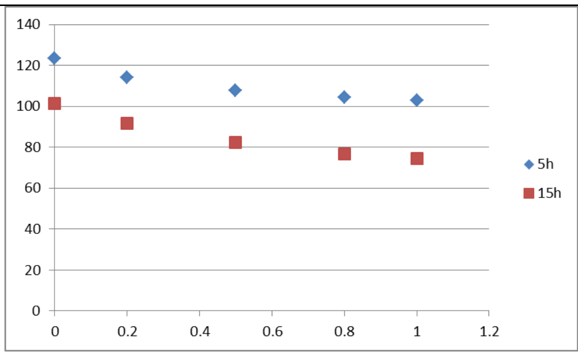
<tr><td></td><td></td></tr>
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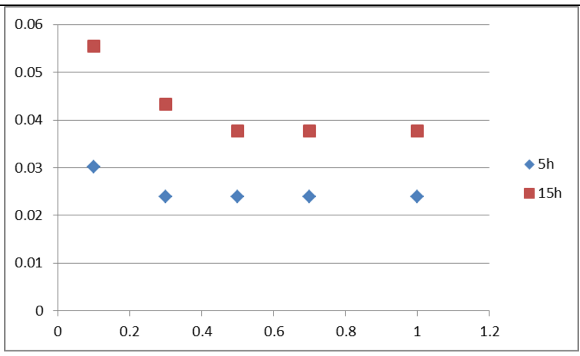
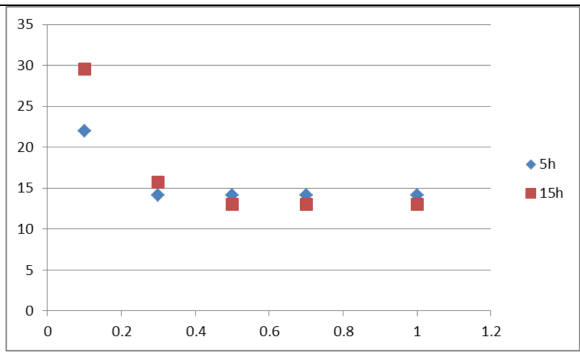
Case 500

X: wetslp

Y: BSS

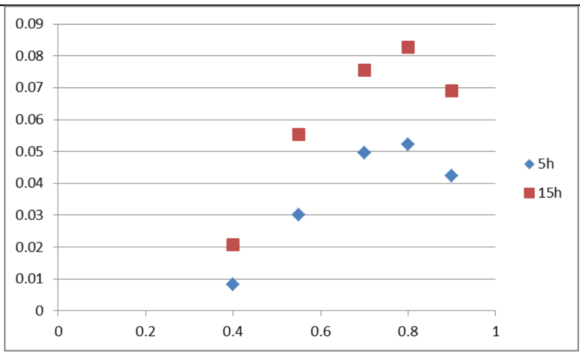


Y: Eroded Volume %

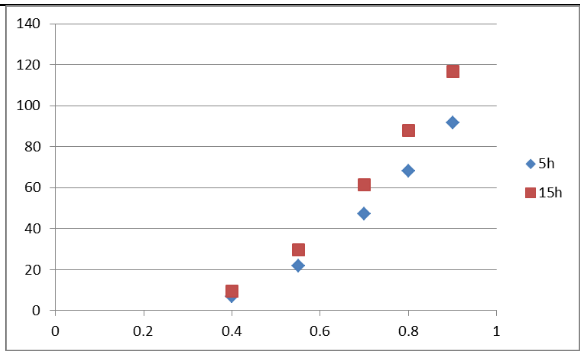


X: Gamma

Y: BSS

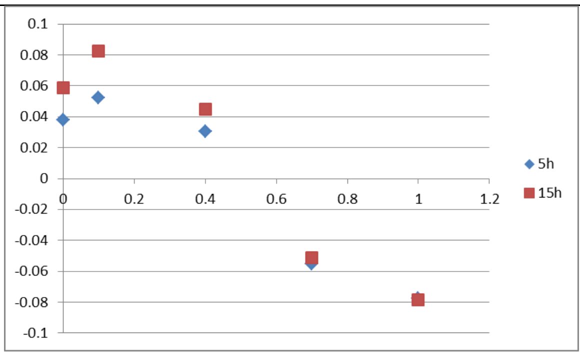


Y: Eroded Volume %

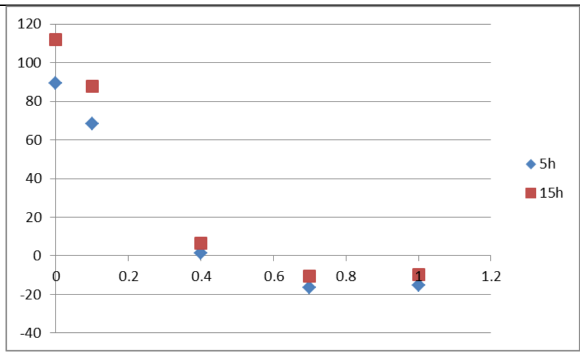


X: Facua

Y: BSS



Y: Eroded Volume %



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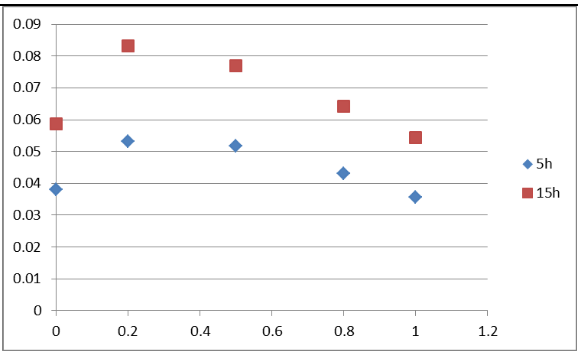
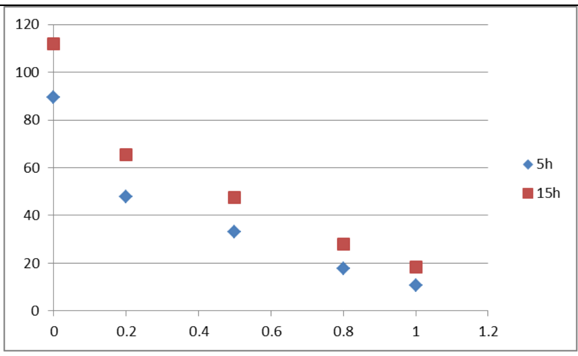
<tr><td>
</td><td>
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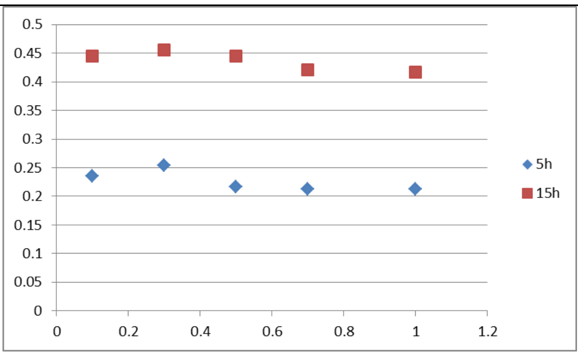
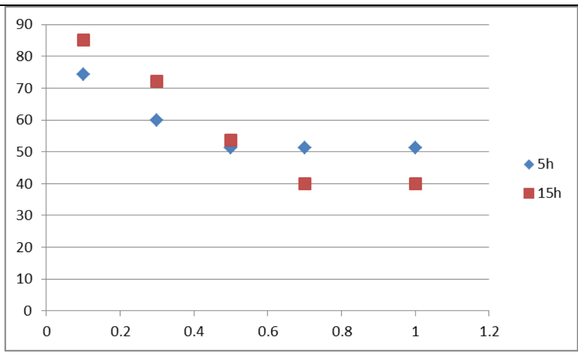
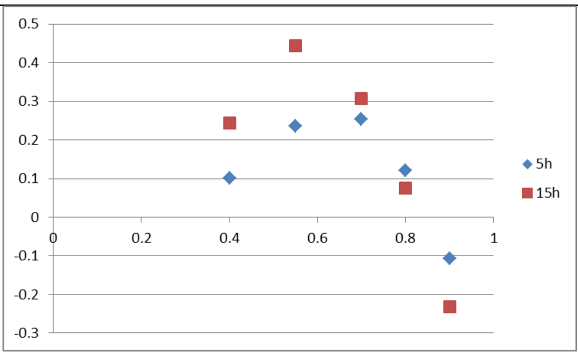
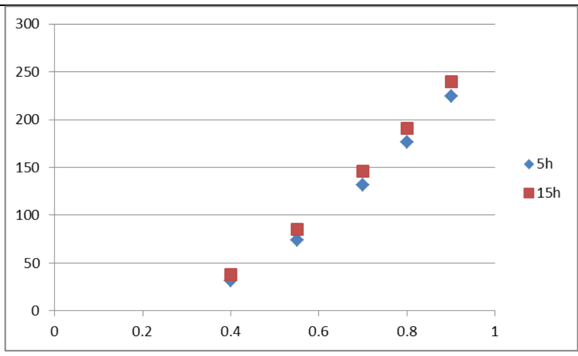
Case 401

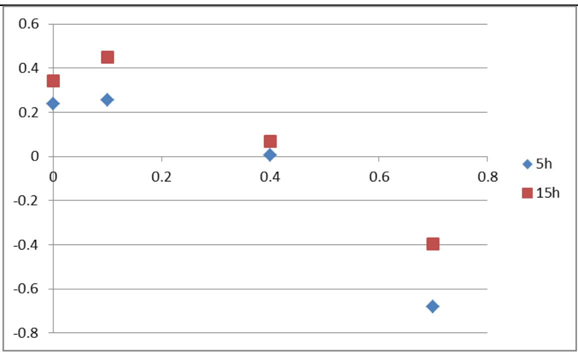
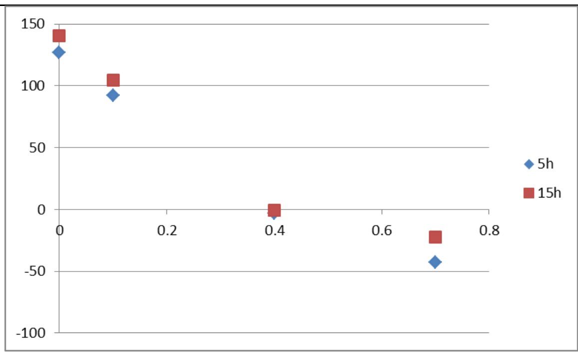
X: wetslp

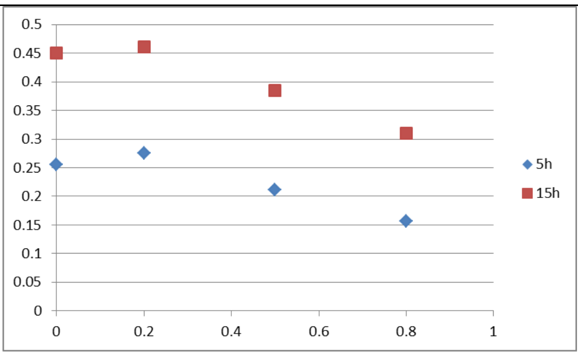
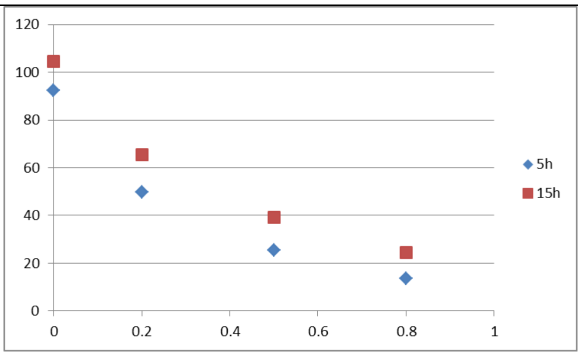
Y: BSS	Y: Eroded Volume %
	

X: Gamma

Y: BSS	Y: Eroded Volume %
	

X: Facua

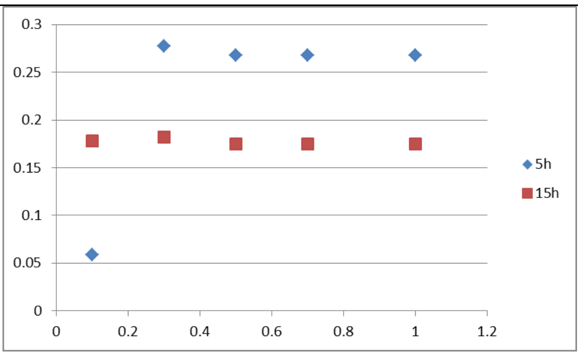
Y: BSS	Y: Eroded Volume %
	

X: Fw	
Y: BSS	**Y: Eroded Volume %**
	

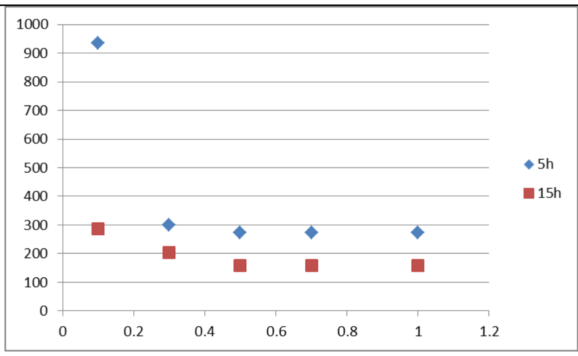
Case 501

X: wetslp

Y: BSS

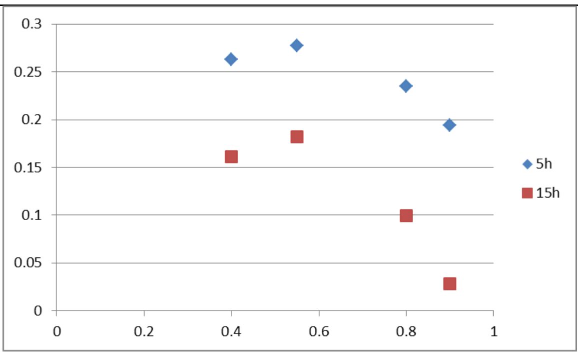


Y: Eroded Volume %

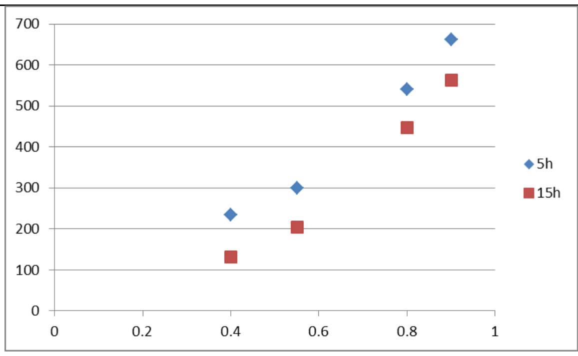


X: Gamma

Y: BSS

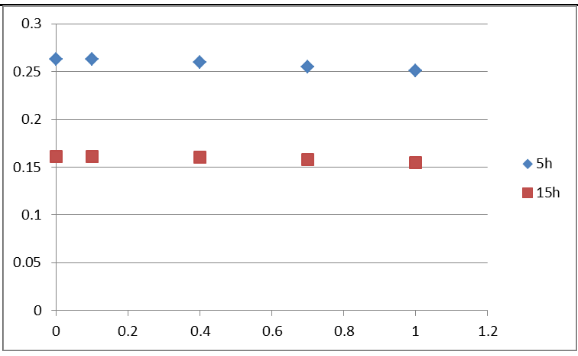


Y: Eroded Volume %

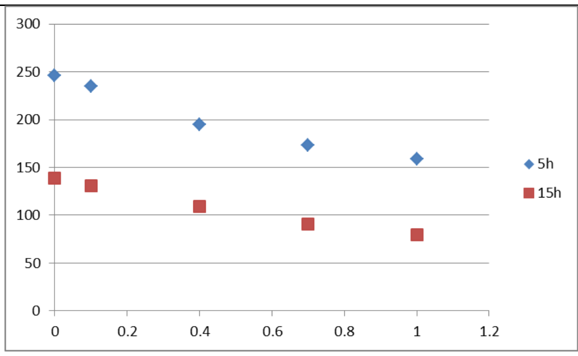


X: Facua

Y: BSS



Y: Eroded Volume %



<table>
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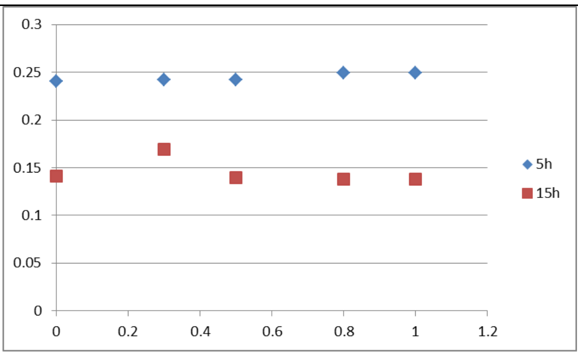
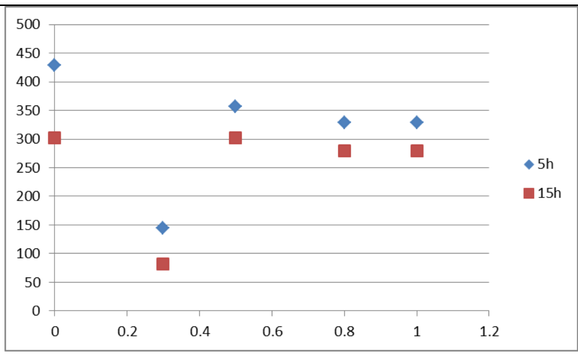
<tr><td>
</td><td>
</td></tr>
</table>

Appendix E-3: DUNERULE Storm Duration Accuracy Calibration

DUNERULE INPUT

Case	sediment Size d50 (m)	(slope from waterline to 8m depth contour) Slope surf zone tanb (-)	Offshore wave height Hs,o (m)	Wave Period Tp (s)	Offshore wave angle to normal (pos. or neg.) Teta,o (deg.)	Tidal Flood level above mean sea level HWL (m)	Storm surge incl tide and wave setup above mean sea level SSL (m)	Dune height above MSL B (m)
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
500.00	0.000220	0.0667	1.5	3.8	0	0.69	0.69	1.494
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524

DUNERULE OUTPUT

Dune Recession Van Rijn						
Time t (input value) (hours)	erosion volume after 5 hours (m3/m)	mean recession after5 hours (m)	Maximum recession after 5 hours	erosion volume after t hours (m3/m)	mean recession after t hours (m)	maximum recession after t hours (m)
15	13.73	14.91855581	22.37783372	17.09774603	18.58450655	27.87675983
15	11.11	21.53	32.29	13.84	26.8	40.22206103
15	4.636457261	5.766737887	8.65010683	5.77577826	7.2	10.77570571
15	4.186694642	6.807633565	10.21145035	5.215495051	8.5	12.72071964
15	0.721791179	0.589698676	0.884548014	0.899157604	0.7	1.101908828

Appendix E-4: Model Configuration/Parameter Setups for Storm Duration Accuracy

****

* SBEACH model configuration file: Case 300.CFG *

****

A--------------------------- MODEL SETUP ------------------------------A

A.1 RUN TITLE: TITLE

Storm Duration Accuracy Case 300

A.2 INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS

1

A.3 TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY

RELATIVE TO INITIAL PROFILE: NDX, XSTART

100 -28.0416

A.4 GRID TYPE (CONSTANT=0, VARIABLE=1): IDX

0

A.5 COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6 CONSTANT GRID CELL WIDTH: DXC

1.2192

A.7 COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8 NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID

2

A.9 GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD

TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)

2, 99 1, 899

A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT

3000 1.0

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR

8

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)

60 180 300 600 900 1200 1800 2400

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP

1

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH

WILL BE DETERMINED): ELV1, ELV2, ELV3

1.00 0.5 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM

POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF

LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED

EDP1, EDP2, EDP3, REFELV

1.00 0.5 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K

1.75E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS

0.002

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM

0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC

5

B---------------------- WAVES/WATER ELEVATION/WIND -----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE

1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE

0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T

1.68 11.33

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV

60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG

0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN

0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG

0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS

0

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND

0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC

7878 20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV

0

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV

0

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV

30.00

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND

0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND

0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND

0.00

C------------------------------ BEACH ----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN

1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,

LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,

END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,

XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS

0.3

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50

0.22

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX

30.00

D------------------------------ BEACH FILL --------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL

0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE

TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START

AND END OF BEACH FILL: NFILL

0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE

INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E--------------------------- SEAWALL/REVETMENT ----------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL

0

E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.

E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL

0.00

E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL

0

E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.

E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION

AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES

FAILURE: PEFAIL, WEFAIL,HFAIL

0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F

----------------------------------- END ------------------------------------

%%% XBeach parameter settings input file %%%

%%% date: 30-Aug-201612:00 %%%

%%% function: xb_write_params %%%

%%% Calibration parameters %%

wetslp = 0.8

gamma = 0.4

facua = 0.15

fw = 0

%%% Grid parameters %%%

%xbeach/delft3d

gridform = xbeach

depfile = DepSeaLevel.dep

posdwn = -1

alfa = 0

dx = 1.2192

dy = 0

nx = 89

ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90

thetamax = +90

dtheta = 10

thetanaut = 0

%%% Model time %%%

tstart = 0

tstop = 180000

tintg = 3600

tintp = 3600

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rho = 1025

g = 9.81

D50 = 0.00022

```
rhos = 2650
por = 0.3
 %%% Flow boundary conditions%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
front = abs_1d
back = abs_1d
left = 0
right = 0
%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tideloc = 0
zs0 = 0
 %%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
instat = 0
Hrms = 1.68
Trep = 11.33
%%% Morphology Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
morfac = 1
morstart = 0
 %%% Output variables %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 outputformat = netcdf
nglobalvar = 6
zb
zb0
zs
H
hh
Qb

nmeanvar = 3
H
hh
zs
```

DUNERULE INPUT

		(slope						
		from waterline						
		to 8m depth						
		contour)			Offshore			
Case	sediment	Slope	Offshore	Wave	wave angle	Tidal Flood	Dune height	
	Size	surf	wave	Period	to normal	level above	above MSL	Dune Recession Van
		zone	height		(pos. or neg.)	mean sea level		
	d50	tanb	Hs,o	Tp	Teta,o	HWL	B	Time t (input value)
	(m)	(-)	(m)	(s)	(deg.)	(m)	(m)	(hours)
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	1
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	3
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	5
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	10
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	15
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	20
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	30
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	40
300.00	0.000220	0.0667	1.7	11.3	0	1	1.92	50

Appendix E-5: Storm Duration Accuracy Comparison Parameters

Percentage Difference Between Measured and Calculated Volume of Sediment Eroded Above Sea Level for different Storm Durations

Case	Model	Storm Durations														
		1	3	5	10	15	20	30	40	50	60	66	70	80	90	100
300	SBEACH	49.34	71.78	84.61	86.51	100.58	113.83	138.13	159.25	183.42						
	XBEACH		172.70	143.95	93.14	83.99	80.13	76.95	76.07	78.86						
	DUNERULE		163.21	161.44	107.88	100.40	98.80	100.14	103.04	110.08						
400	SBEACH	62.17	79.32	67.76	91.47	97.55	104.25	115.28	121.94							
	XBEACH			123.69	114.96	101.47	97.11	94.03	93.09							
	DUNERULE	199.50	158.57	115.18	111.11	99.55	95.38	91.19	88.48							
500	SBEACH		89.24	109.68	130.64	143.07	131.77	124.65	118.18	114.40	107.51		87.60	88.22	84.11	72.80
	XBEACH		58.25	70.79	83.32	91.53	85.81	84.43	83.88	83.08	79.82		66.92	69.35	67.31	59.86
	DUNERULE		111.08	118.26	101.29	99.95	82.73	72.72	63.89	58.50	52.18		42.05	42.06	39.75	35.24
401	SBEACH	39.55	74.13	91.04	95.59	86.57	83.76	66.95	62.39	59.20	62.34	64.46				
	XBEACH	47.85	80.90	92.86	110.38	103.83	111.68	107.86	115.57	123.06	142.41	152.60				
	DUNERULE	138.04	164.66	160.95	130.72	100.25	94.09	75.34	74.73	70.02	71.09	73.30				
501	SBEACH	0.00	126.90	144.71	119.08	81.32	56.51	41.16	28.99	21.65	18.52					
	XBEACH	0.00	201.13	178.99	139.89	97.56	68.73	50.91	36.21	27.23	23.42					
	DUNERULE		150.45	161.86	131.24	100.82	77.66	61.09	46.36	36.00	31.77					

Number of Calculated Results per Percentage Group for each Numerical Model

Group	Model	Count	Group	Model	Count	Group	Model	Count	Group	Model	Count
90-110%	SBEACH	8	75-90% & 110-125%	SBEACH	17	50-75% & 125-150%	SBEACH	17	<50% & >150%	SBEACH	9
	XBEACH	10		XBEACH	17		XBEACH	12		XBEACH	9
	DUNERULE	13		DUNERULE	9		DUNERULE	12		DUNERULE	15

Percentage Difference Between Measured and Calculated Recession of Shoreline for different Storm Durations

Case	Model	Storm Durations														
		1	3	5	10	15	20	30	40	50	60	66	70	80	90	100
300	SBEACH	25.00	35.71	41.18	47.83	55.56	65.52	95.99	118.52	140.35						
	XBEACH	258.85	149.53	120.09	91.11	77.70	75.19	79.75	80.80	80.42						
	DUNERULE	205.21	203.11	215.94	183.34	169.37	167.03	194.55	206.08	215.48						
400	SBEACH	58.59	81.82	102.53	112.50	95.45	104.55	103.70	103.57							
	XBEACH	195.15	149.16	166.67	112.50	121.93	113.22	104.33	93.09							
	DUNERULE	338.39	372.97	441.38	380.26	299.91	317.68	280.71	286.72							
500	SBEACH	0.00	75.00	100.48	109.61	115.38	114.83	106.14	104.47	94.52	100.66		89.24	88.46	92.75	92.59
	XBEACH	0.00	75.95	99.89	117.89	100.47	100.16	98.45	95.62	94.44	96.12		87.65	88.75	89.76	90.86
	DUNERULE	0.00	137.39	177.37	148.18	135.97	133.74	119.44	113.20	107.09	106.02		96.22	95.02	97.29	95.68
401	SBEACH	51.85	64.29	100.00	104.62	95.24	96.82	84.85	80.63	79.11	81.08	72.97				
	XBEACH	55.96	93.47	108.91	118.17	102.60	108.28	113.91	119.22	126.48	134.89	126.26				
	DUNERULE	124.86	185.36	209.39	192.42	149.05	150.70	141.00	141.05	144.29	152.97	140.32				
501	SBEACH	0.00	0.00	0.00	73.33	36.67	31.43	24.44	24.44	18.33	18.33					
	XBEACH	0.00	0.00	116.91	127.41	65.93	57.64	45.81	46.34	35.02	35.22					
	DUNERULE	0.00	0.00	0.00	83.34	45.19	41.03	34.61	36.66	28.75	29.81					

Number of Calculated Results per Percentage Group for each Numerical Model

Group	Model	Count	Group	Model	Count	Group	Model	Count	Group	Model	Count
90-110%	SBEACH	18	75-90% & 110-125%	SBEACH	12	50-75% & 125-150%	SBEACH	8	<50% & >150%	SBEACH	14
	XBEACH	15		XBEACH	18		XBEACH	9		XBEACH	10
	DUNERULE	7		DUNERULE	3		DUNERULE	10		DUNERULE	32

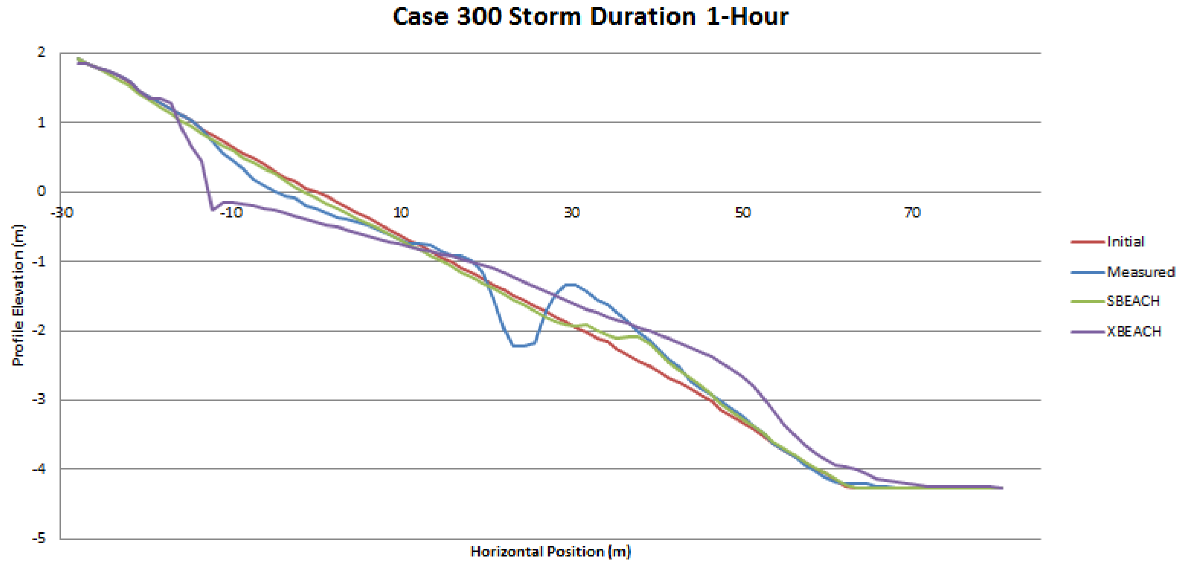
Brier Skill Score (BSS) between Measured and Calculated Beach Profiles for different Storm Durations

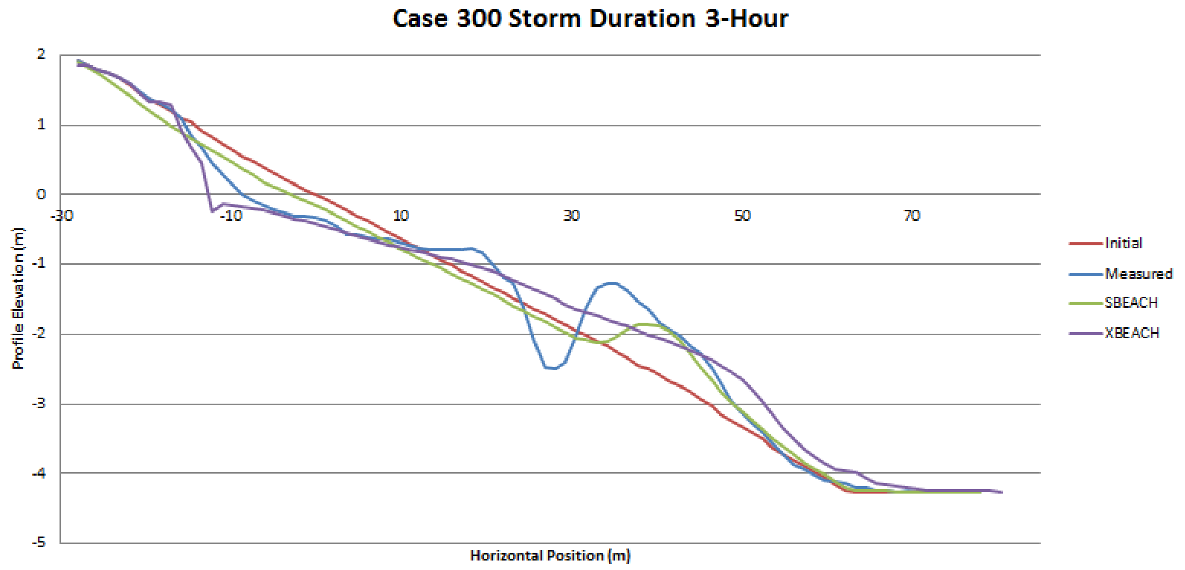
Case	Model	Storm Durations														
		1	3	5	10	15	20	30	40	50	60	66	70	80	90	100
300	SBEACH	0.32	0.52	0.68	0.78	0.69	0.55	0.16	-0.10	-0.10						
	XBEACH	-0.10	0.12	0.33	0.42	0.32	0.22	0.18	0.17	0.31						
400	SBEACH	0.50	0.65	0.47	0.63	0.67	0.73	0.80	0.85							
	XBEACH	-0.10	0.29	0.80	0.78	0.78	0.77	0.77	0.78							
500	SBEACH	0.36	0.28	0.19	0.21	0.25	0.25	0.16	0.22	0.22	0.19		0.15	0.12	0.11	0.07
	XBEACH	-0.10	0.05	0.05	0.06	0.08	0.12	0.12	0.15	0.17	0.16		0.14	0.13	0.14	0.15
401	SBEACH	0.14	0.45	0.60	0.57	0.73	0.71	0.71	0.65	0.62	0.57	0.56				
	XBEACH	0.04	0.16	0.26	0.36	0.45	0.47	0.54	0.50	0.49	0.44	0.43				
501	SBEACH	0.20	0.42	0.24	0.23	0.17	0.15	0.12	0.04	0.00	0.00					
	XBEACH	0.12	0.49	0.26	0.19	0.16	0.15	0.12	0.06	0.03	0.03					

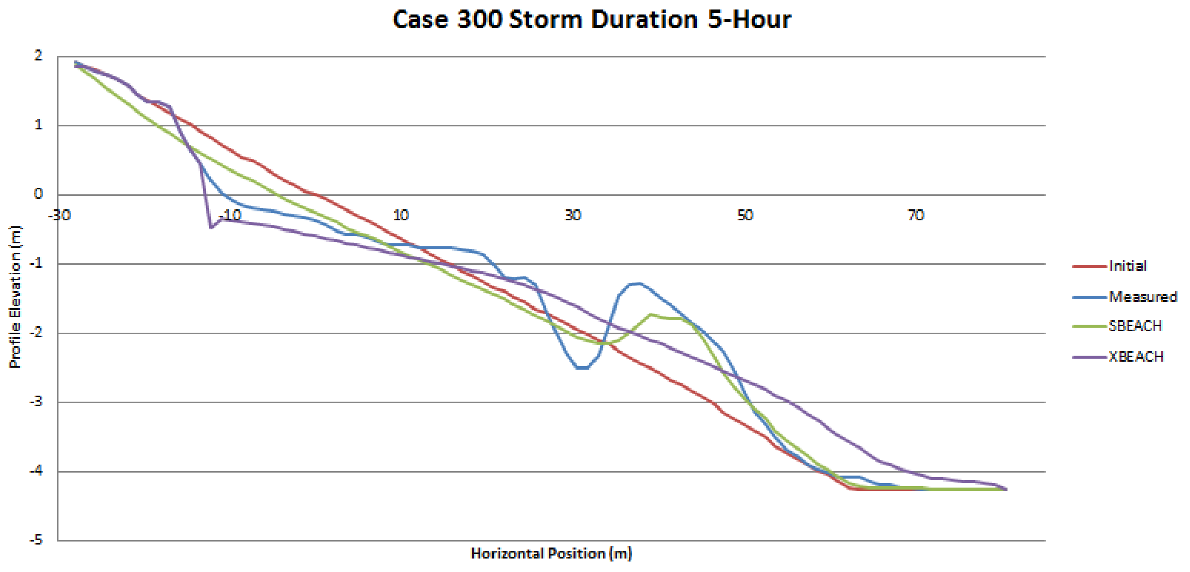
Number of Calculated Results per Percentage Group for each Numerical Model

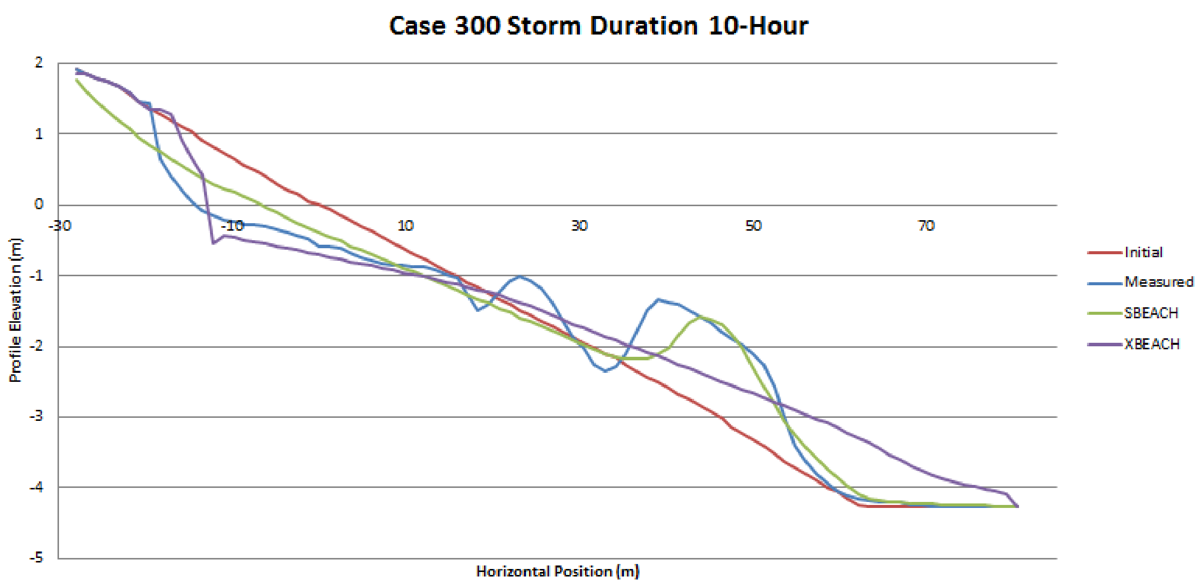
Excellent	SBEACH	2	Good	SBEACH	13	Fair	SBEACH	11	Poor	SBEACH	24	Bad
	XBEACH	1		XBEACH	5		XBEACH	13		XBEACH	30	

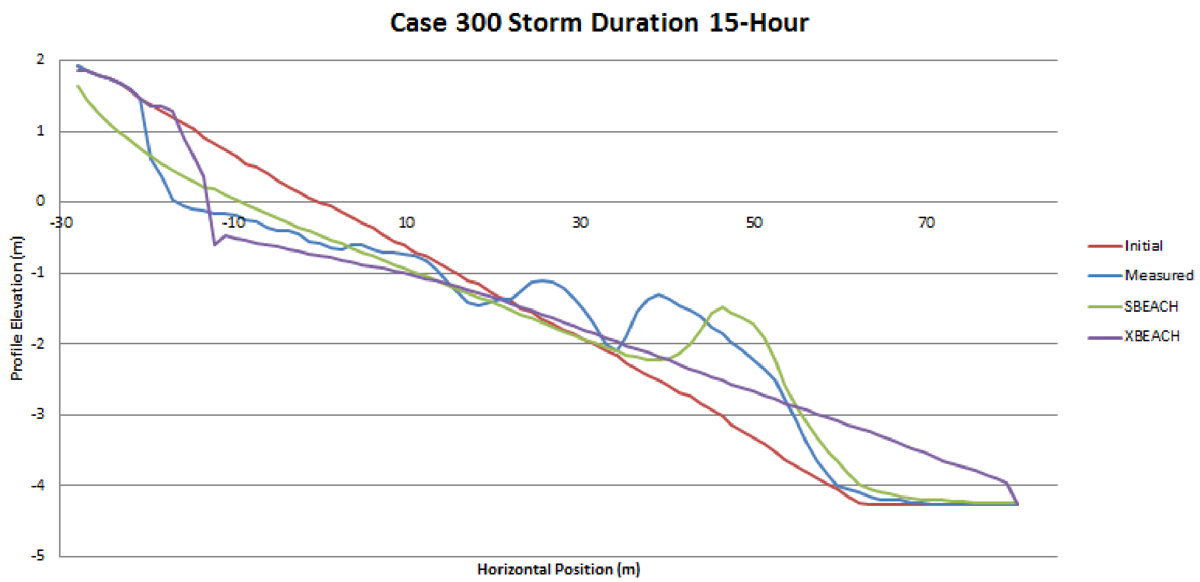
Appendix E-6: Storm Duration Model Accuracy Runs Output

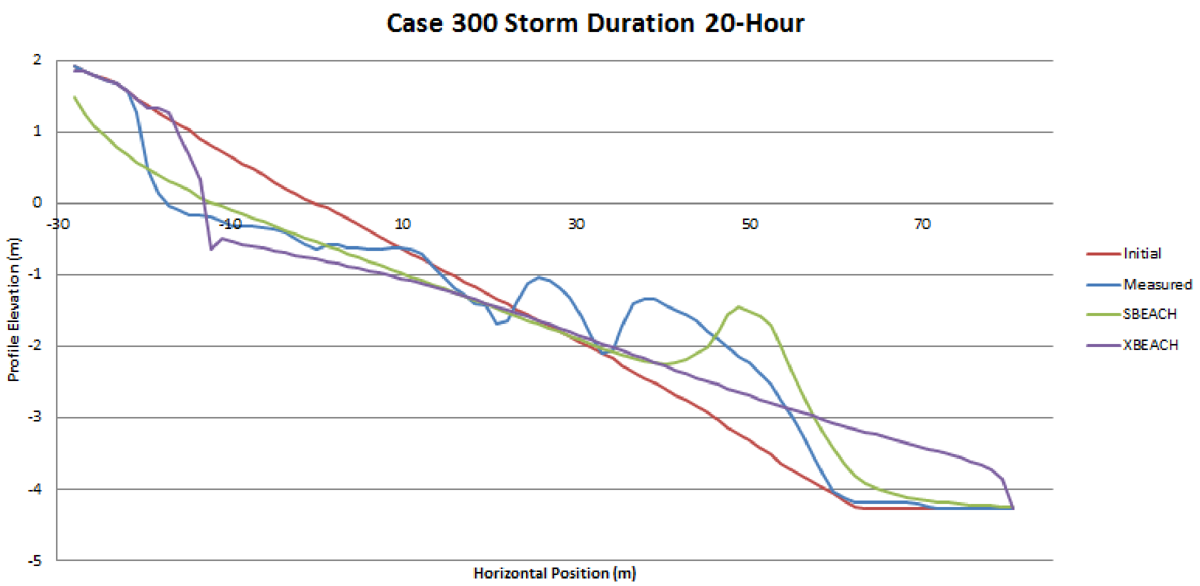


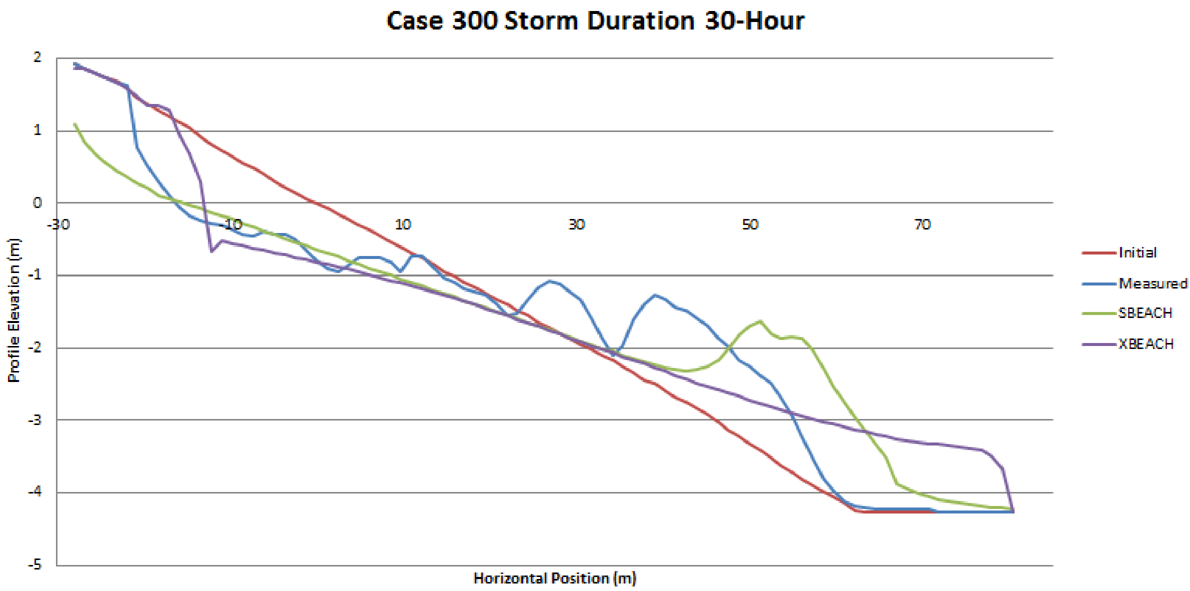


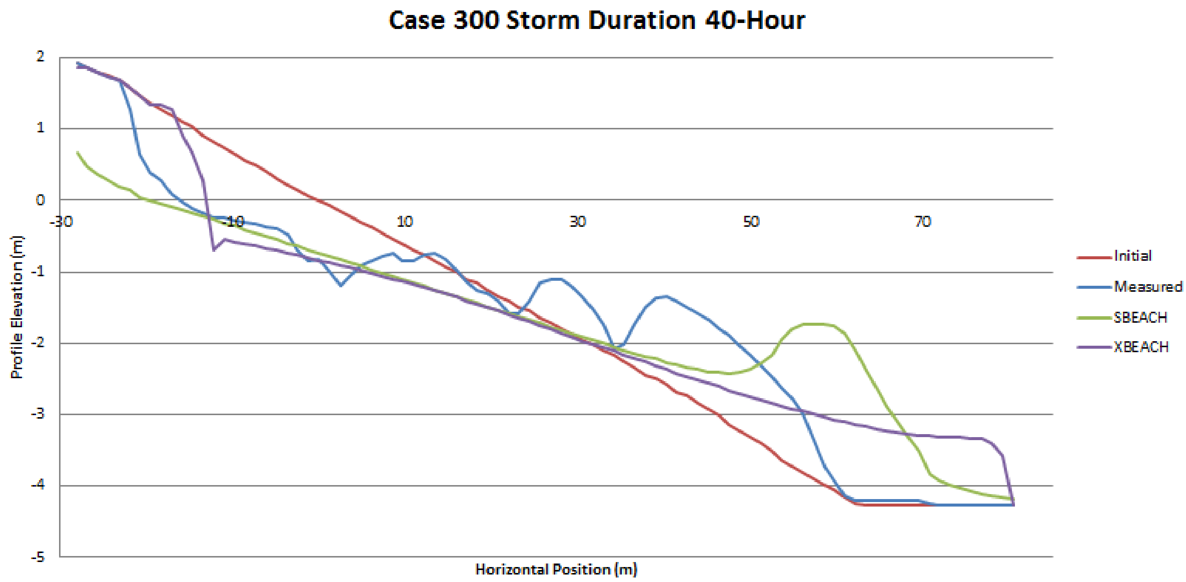


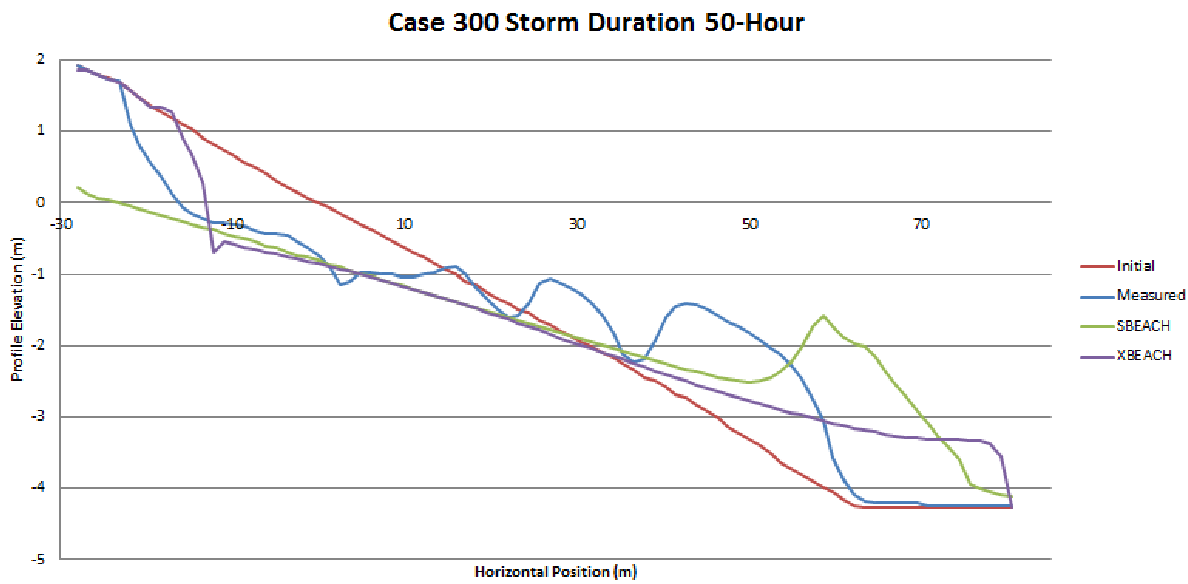

Case 300 Storm Duration 10-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

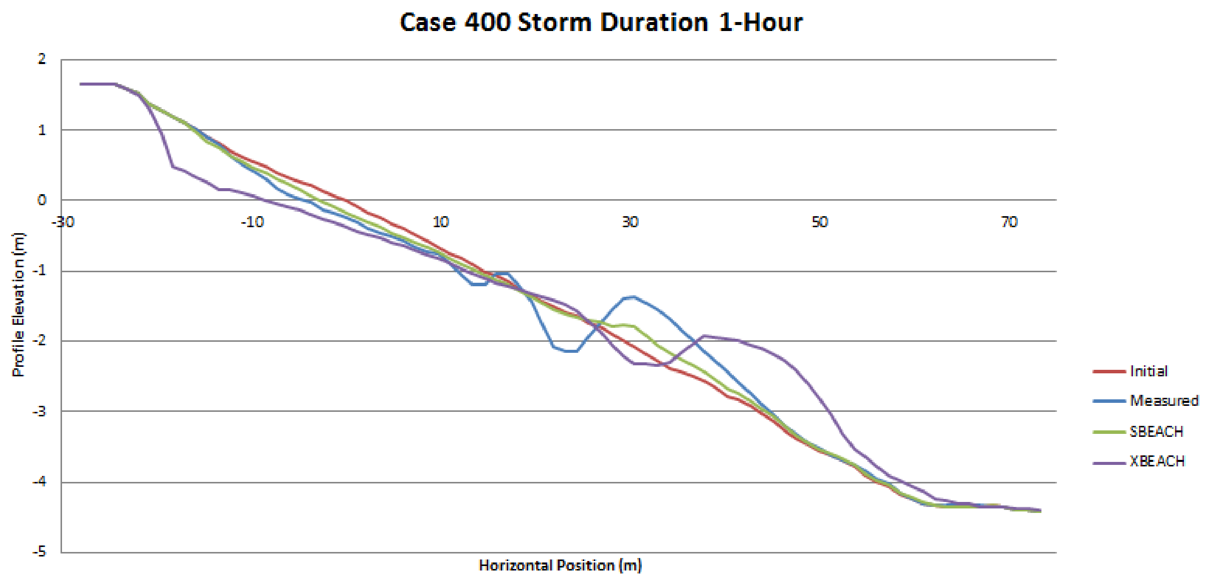

Case 300 Storm Duration 15-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

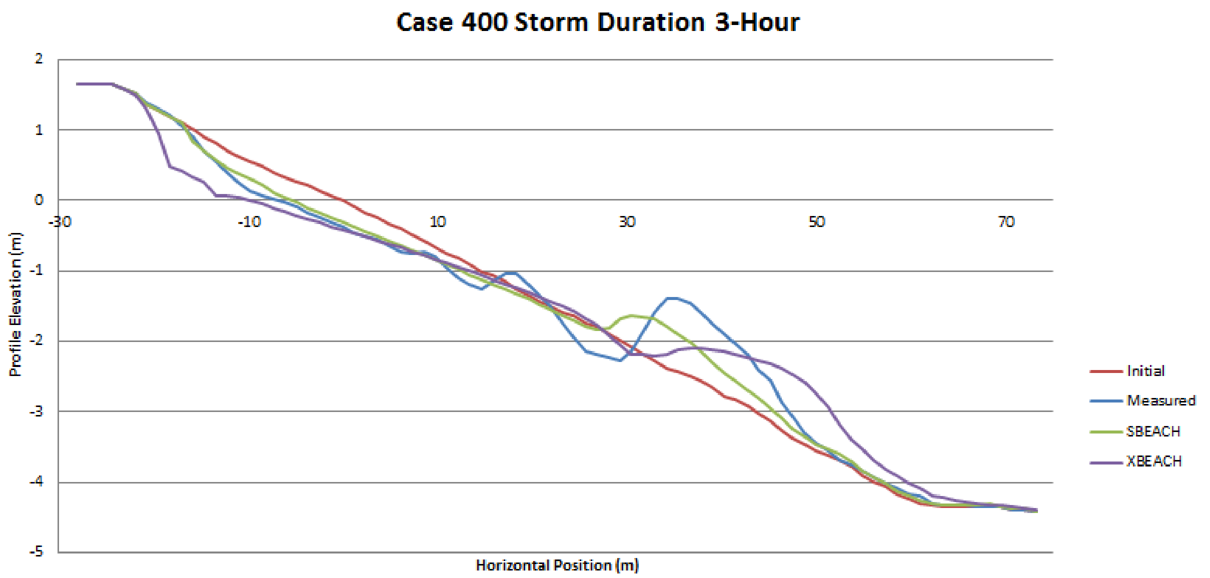

Case 300 Storm Duration 20-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

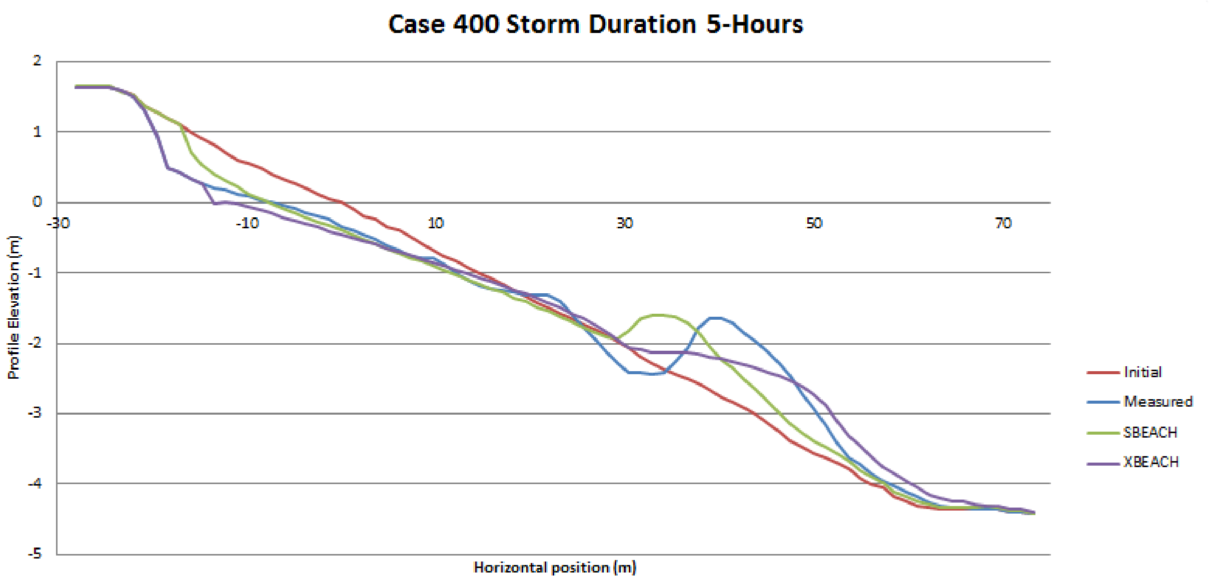

Case 300 Storm Duration 30-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

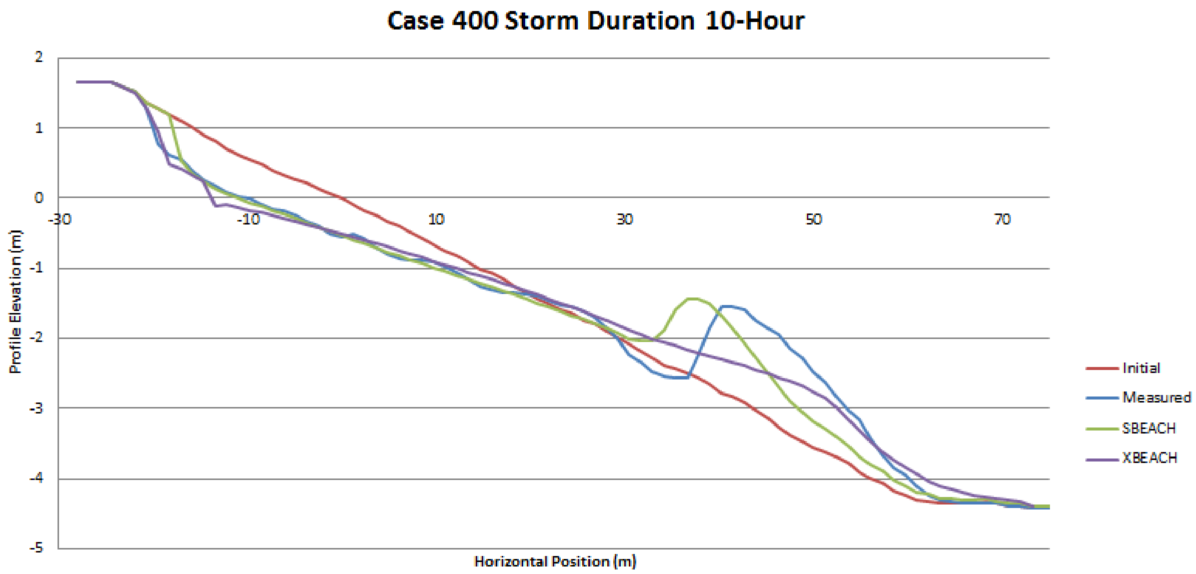

Case 300 Storm Duration 40-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

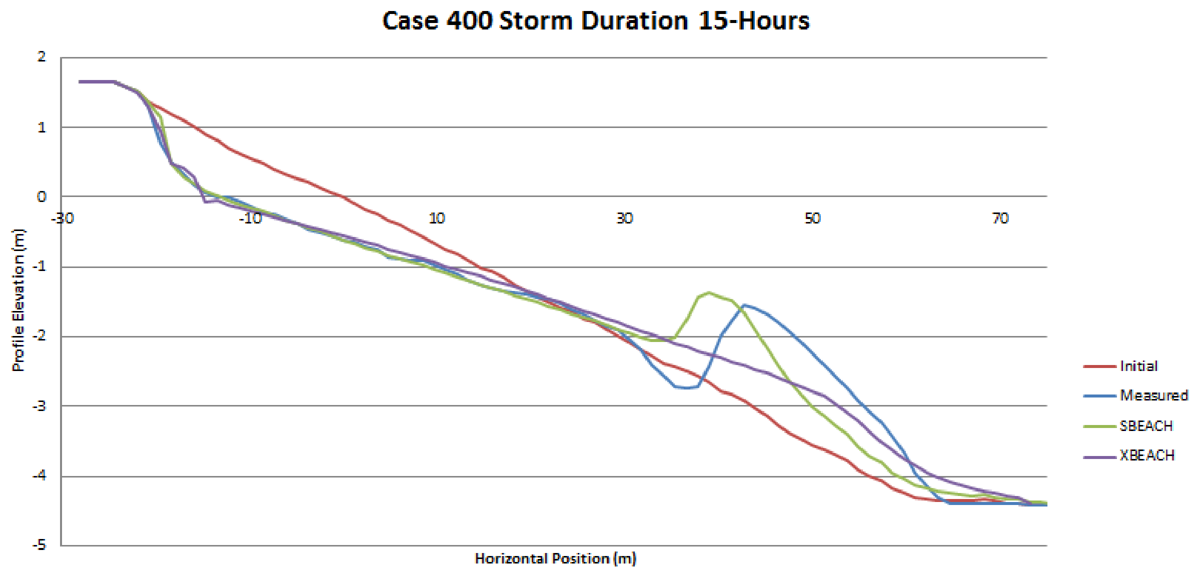

Case 300 Storm Duration 50-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH

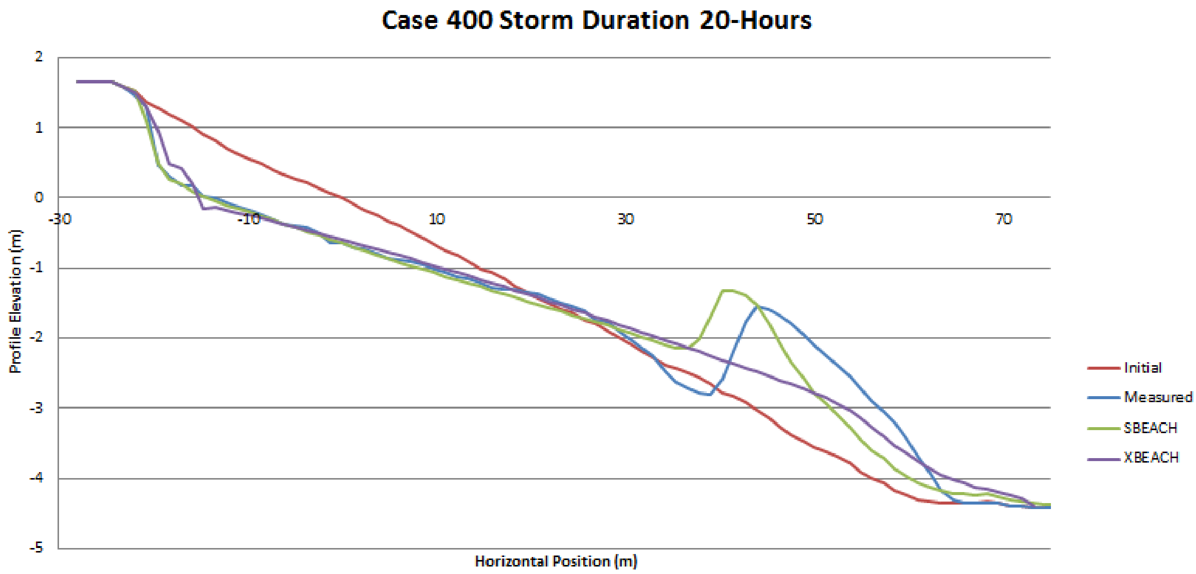

Case 400 Storm Duration 1-Hour
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

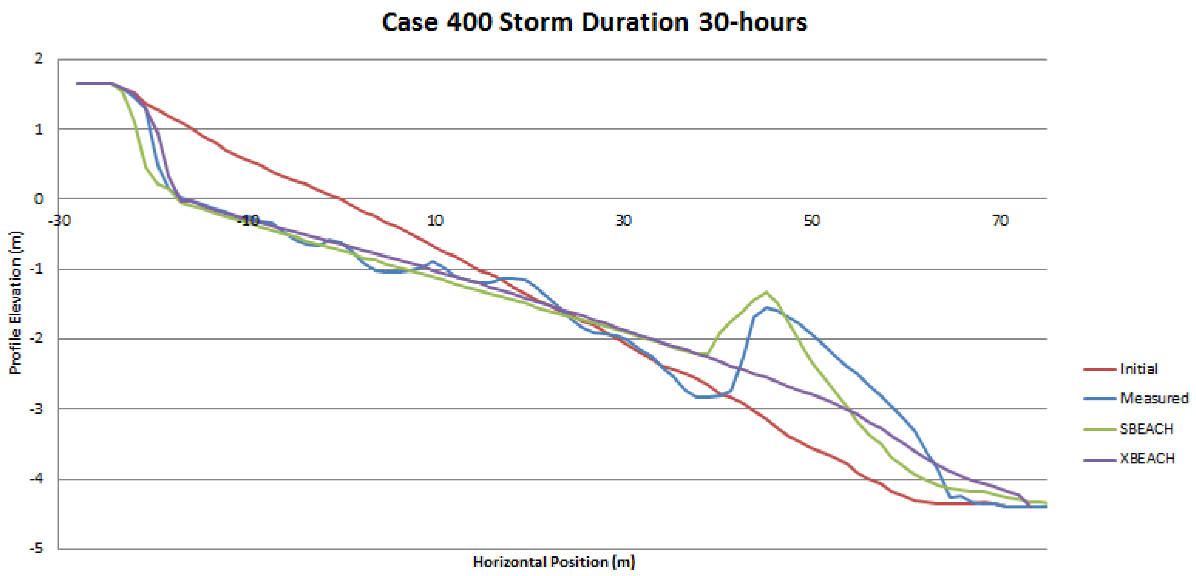

Case 400 Storm Duration 3-Hour
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Case 400 Storm Duration 5-Hours
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal position (m)
Initial
Measured
SBEACH
XBEACH

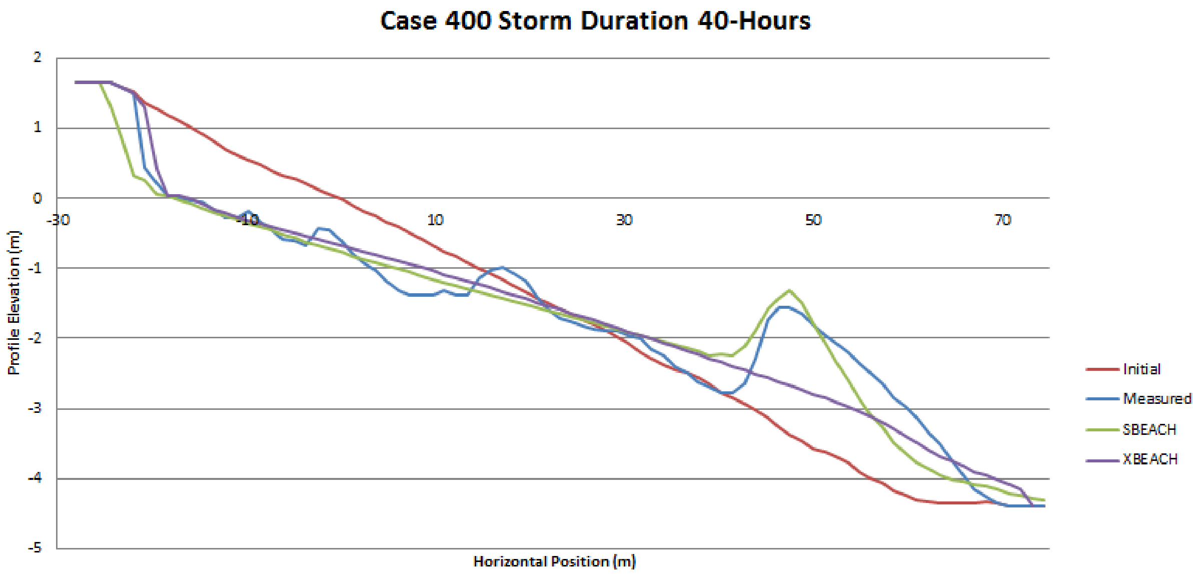

Case 400 Storm Duration 10-Hour
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Case 400 Storm Duration 15-Hours
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

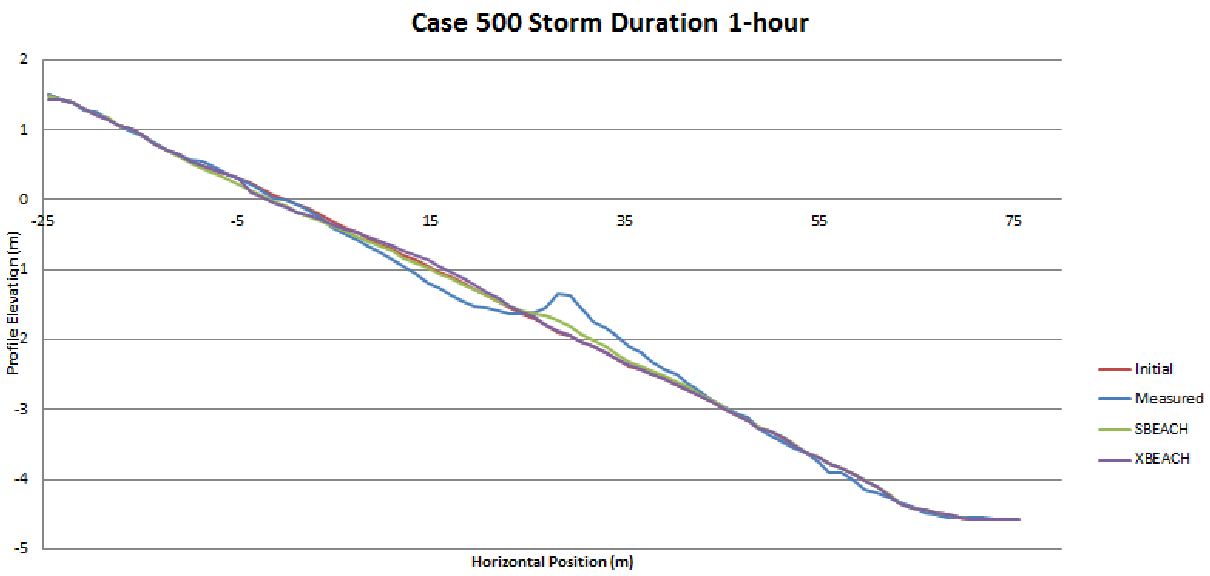

Case 400 Storm Duration 20-Hours
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH



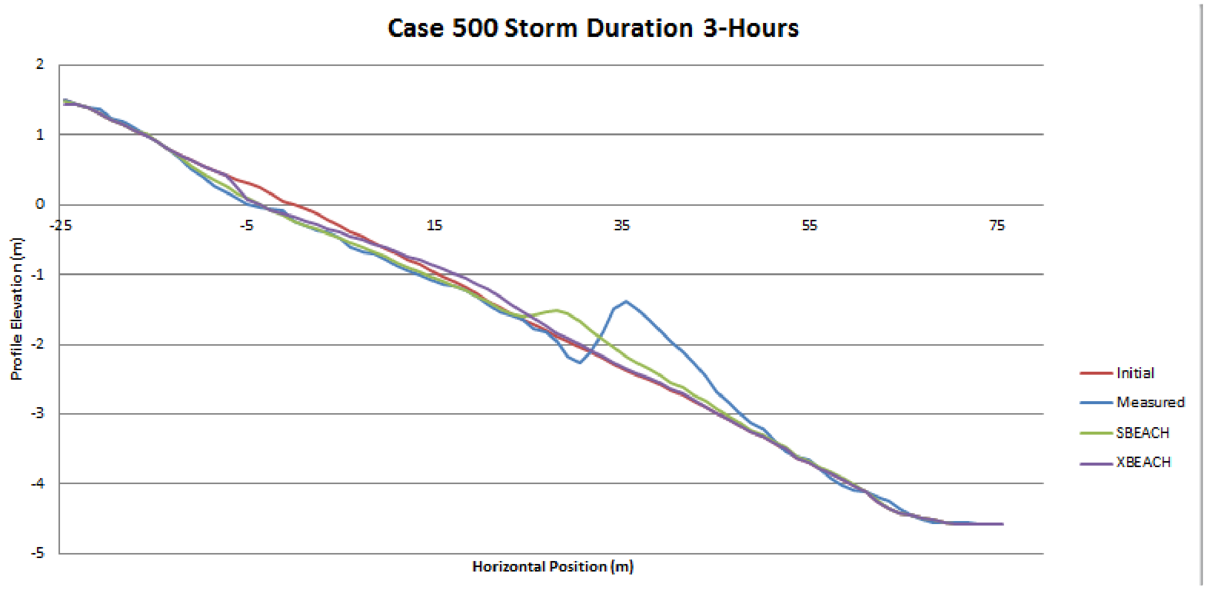
Case 400 Storm Duration 30-hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH



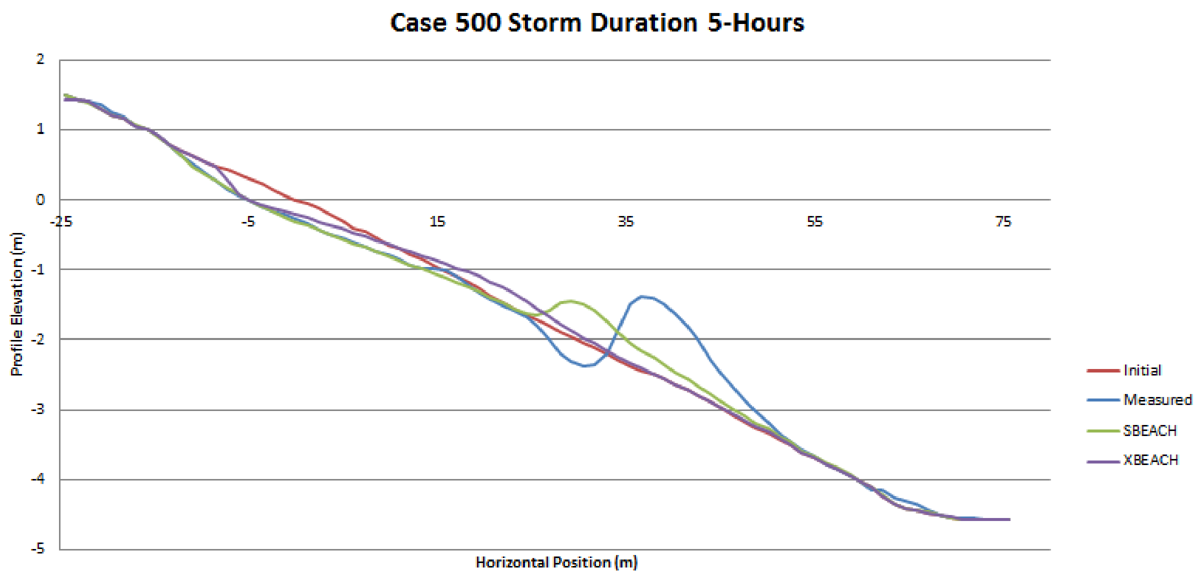
Case 400 Storm Duration 40-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
SBEACH
XBEACH



Case 500 Storm Duration 1-hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Initial
Measured
SBEACH
XBEACH

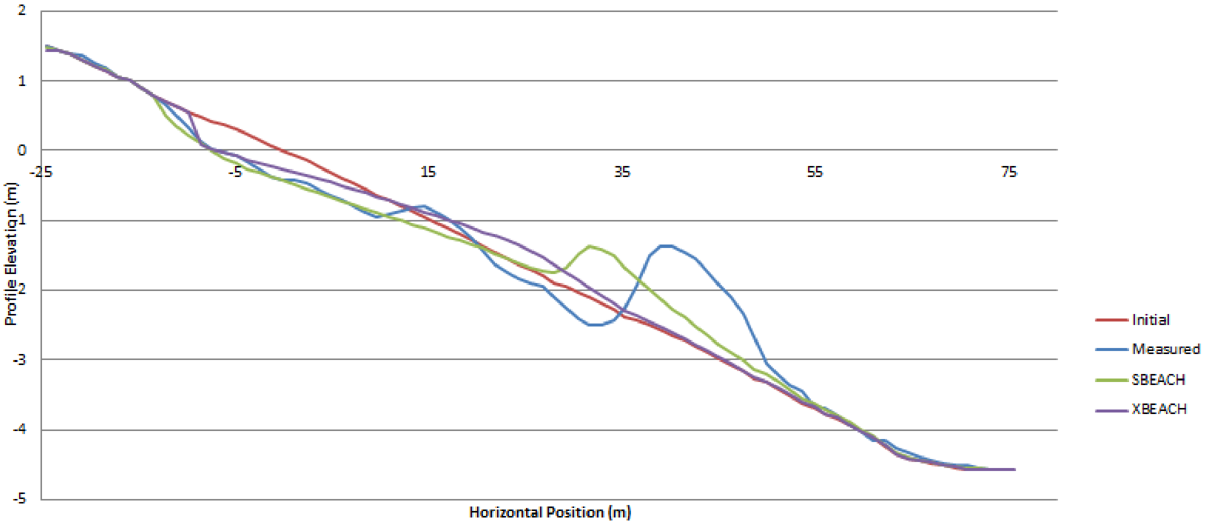


Case 500 Storm Duration 3-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Initial
Measured
SBEACH
XBEACH

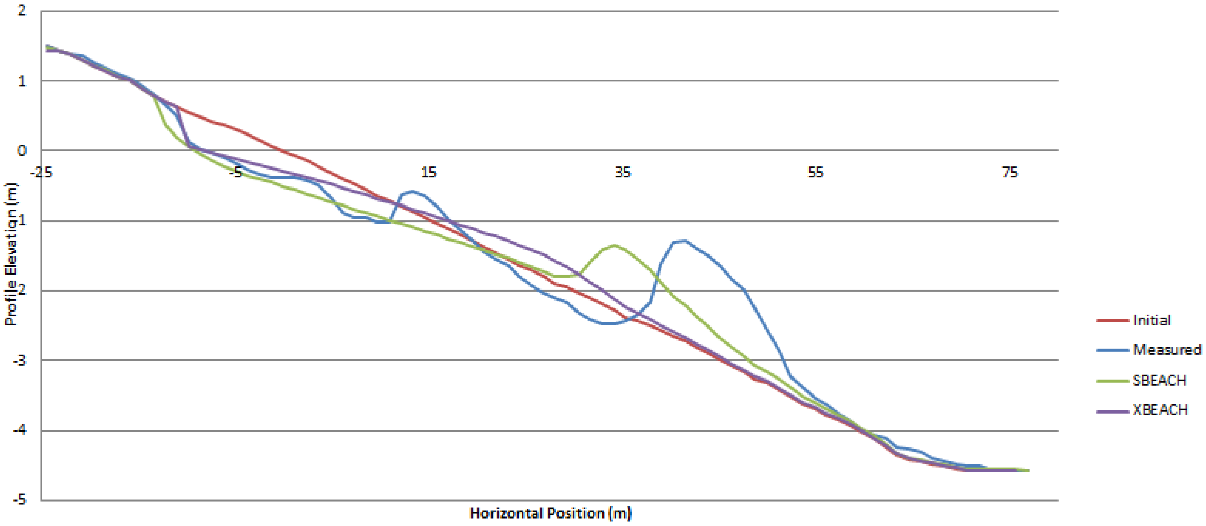


Case 500 Storm Duration 5-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Initial
Measured
SBEACH
XBEACH

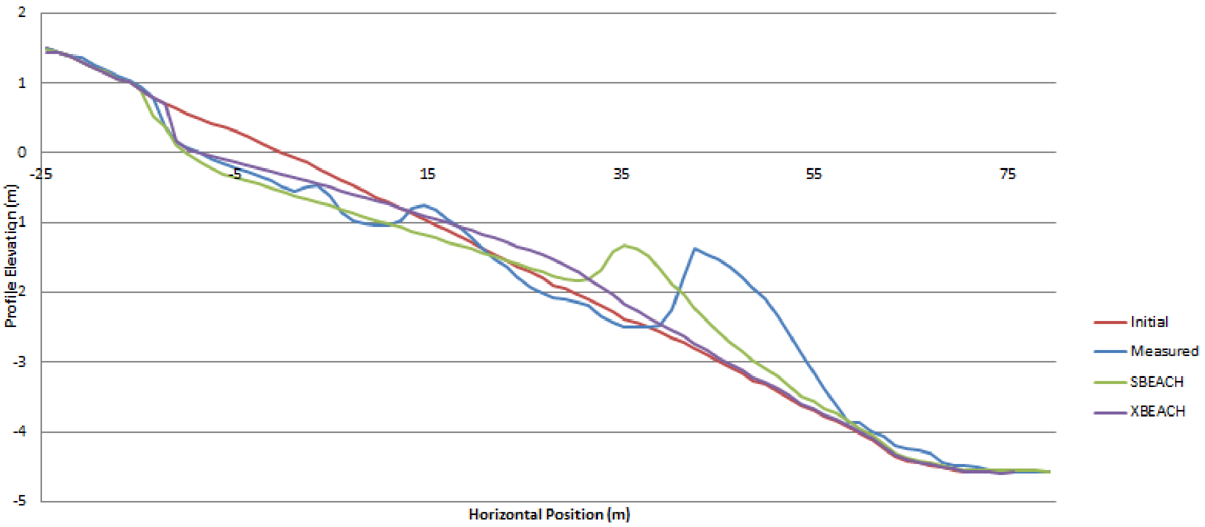
Case 500 Storm Duration 10-Hours

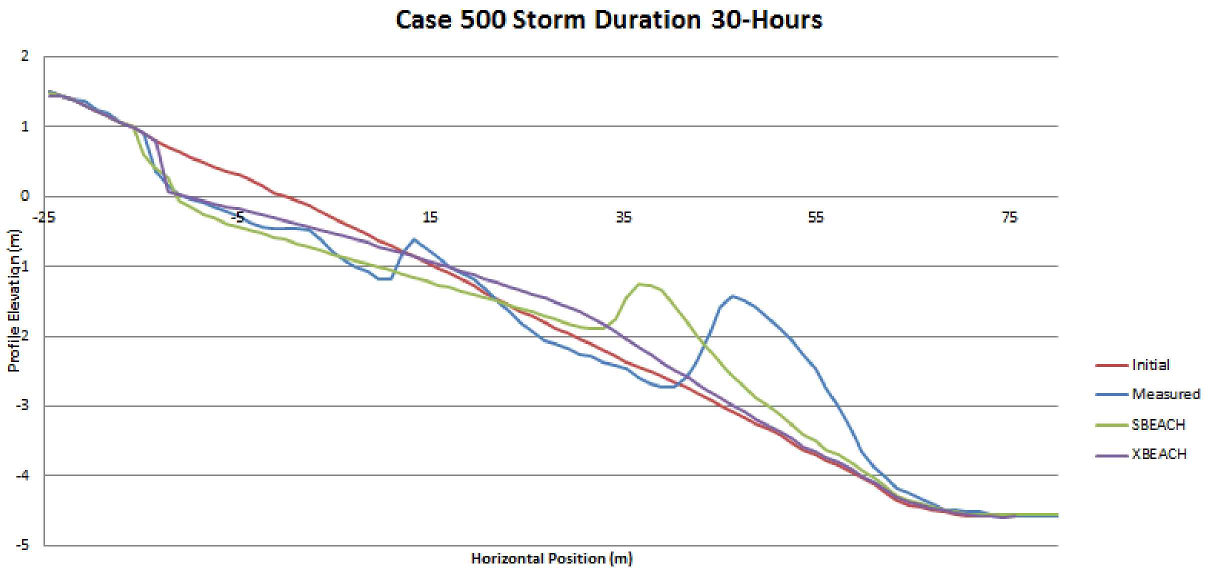


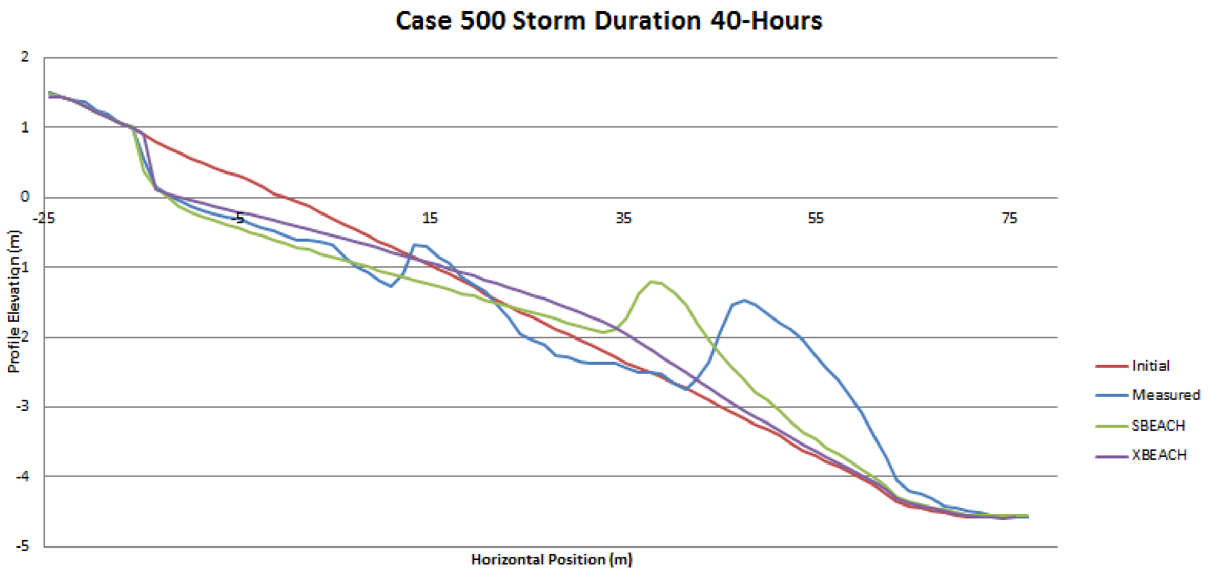
Case 500 Storm Duration 15-Hours

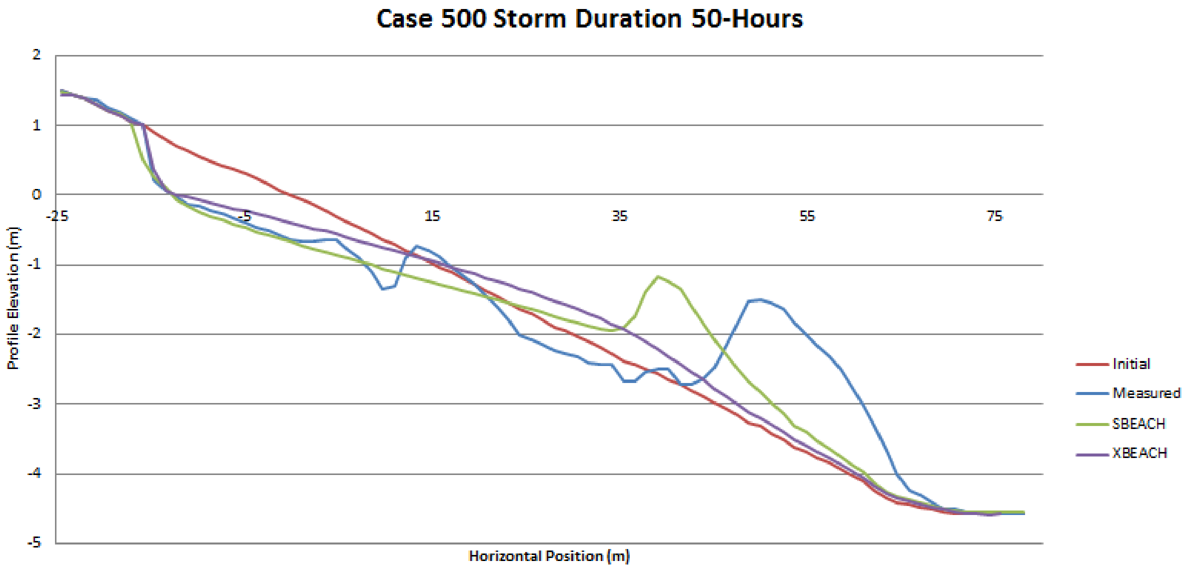


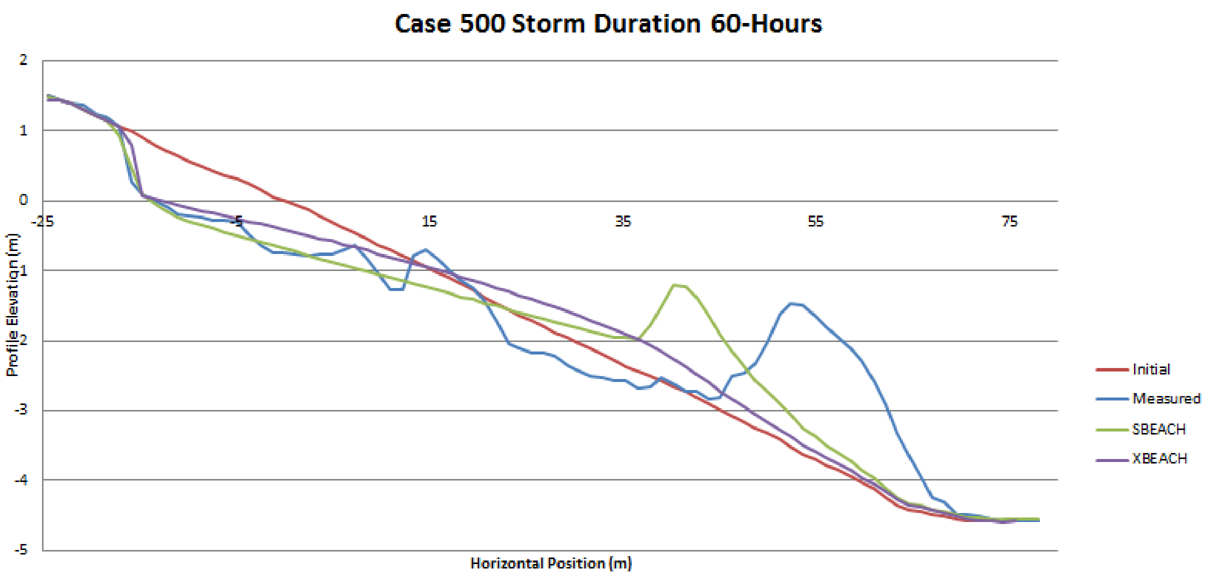
Case 500 Storm Duration 20-Hours



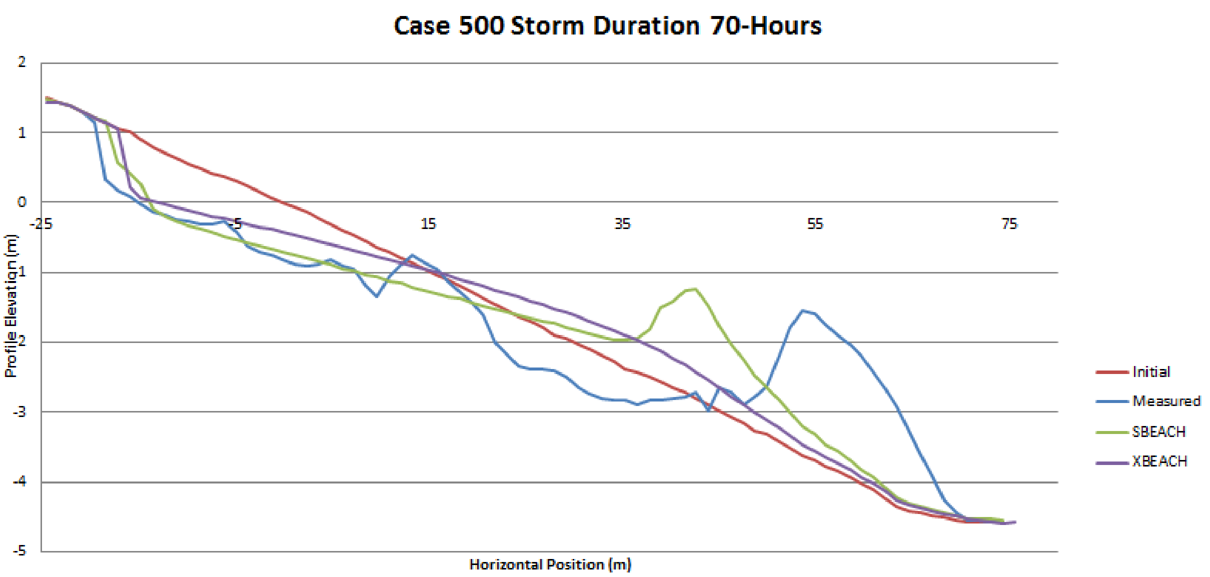

Case 500 Storm Duration 30-Hours
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH


Case 500 Storm Duration 40-Hours
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

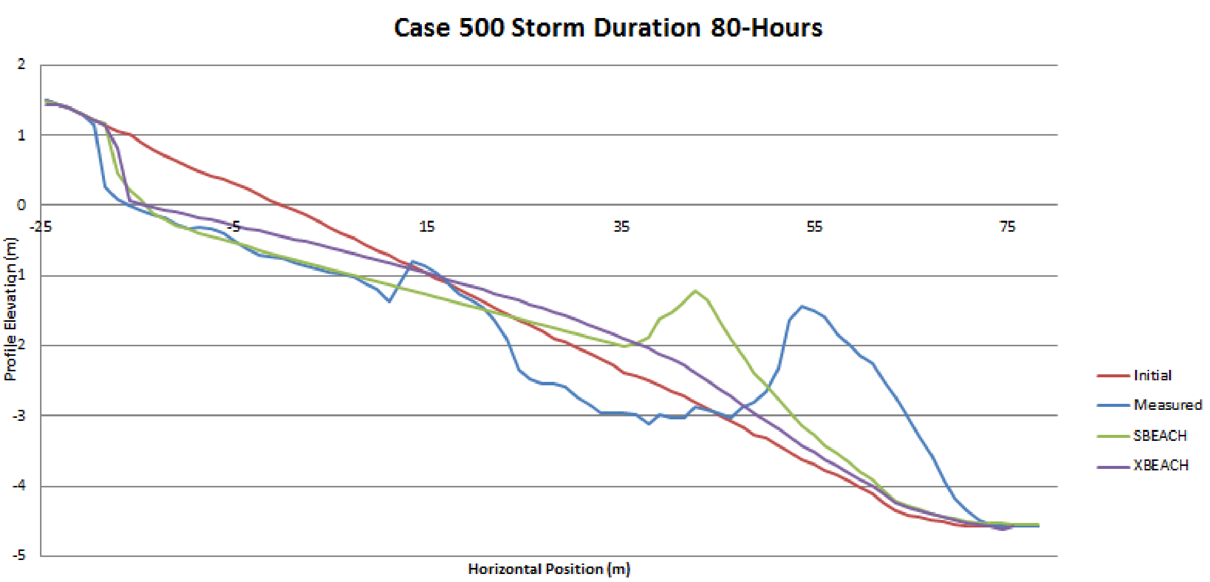

Case 500 Storm Duration 50-Hours
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH



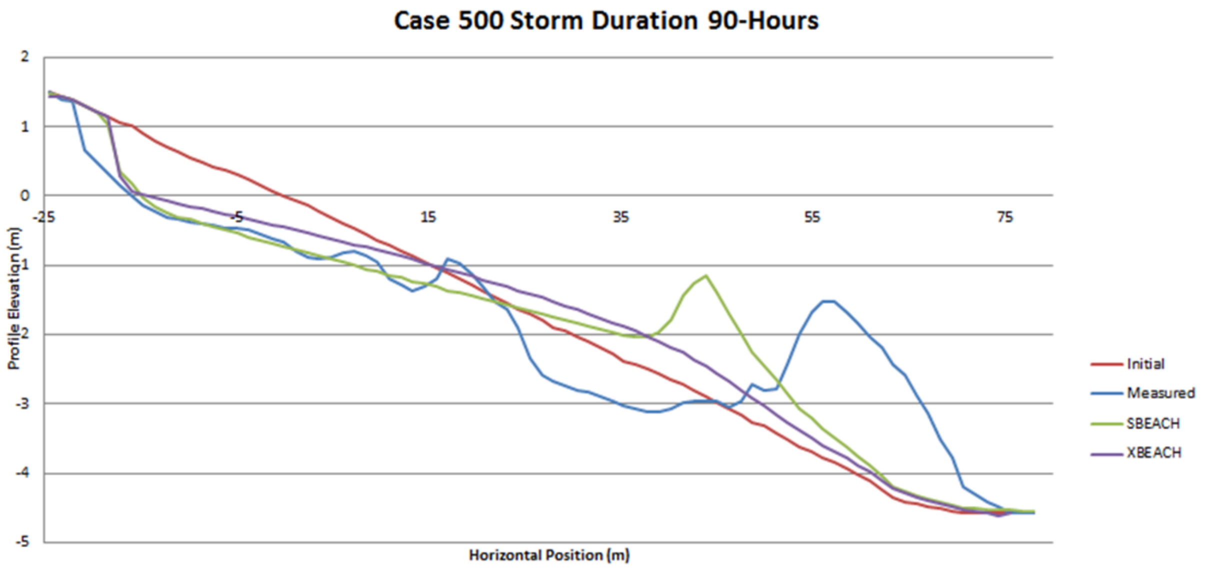
Case 500 Storm Duration 60-Hours
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH



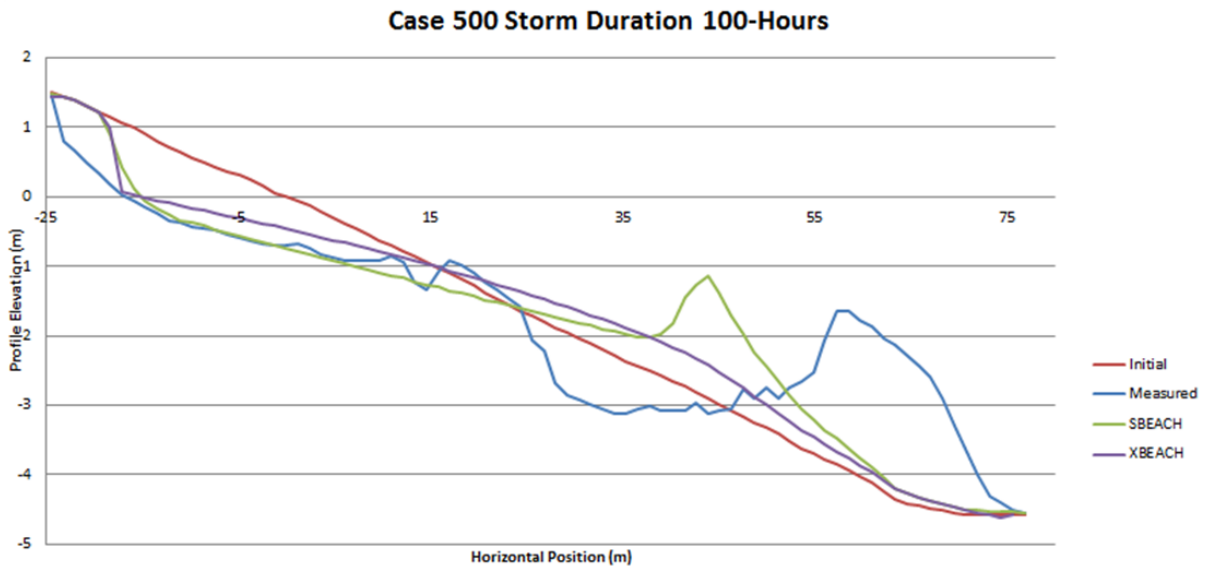
Case 500 Storm Duration 70-Hours
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH



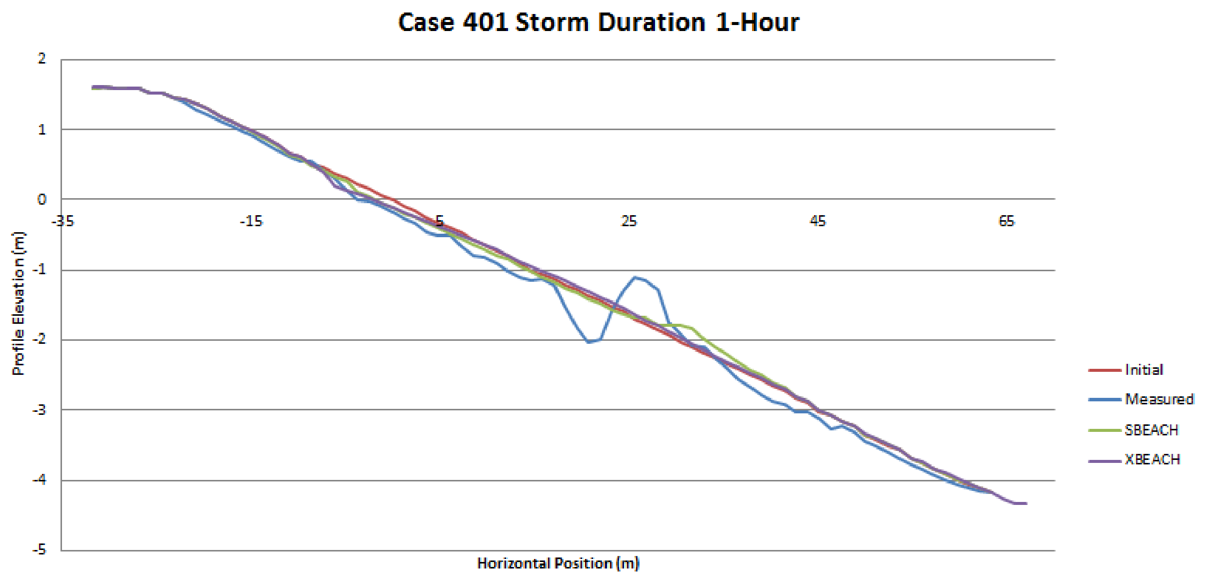
Case 500 Storm Duration 80-Hours
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

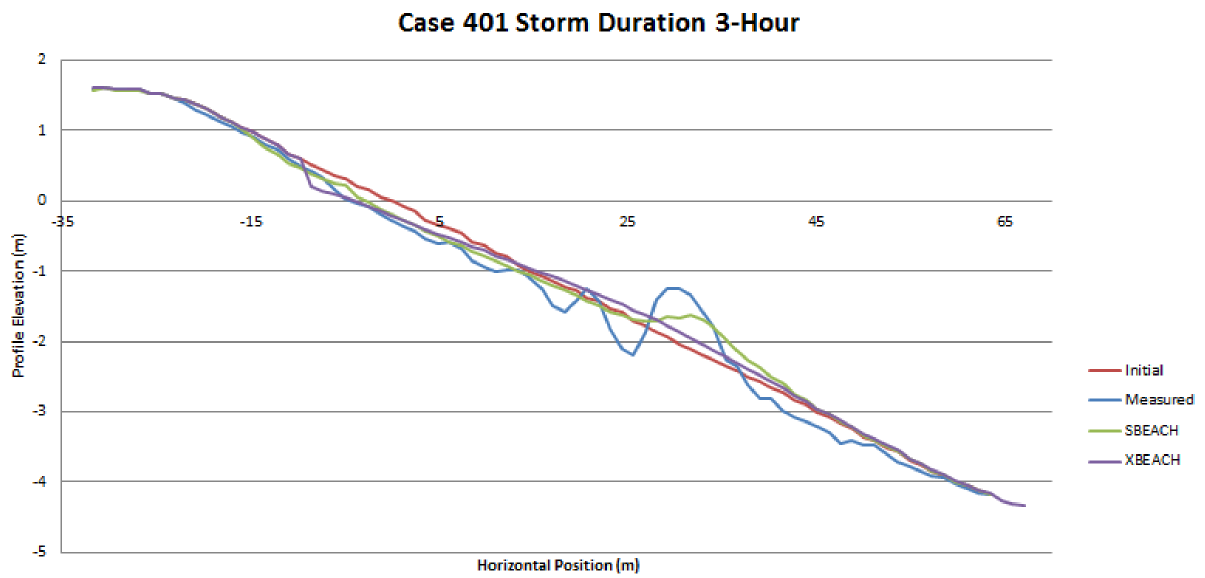


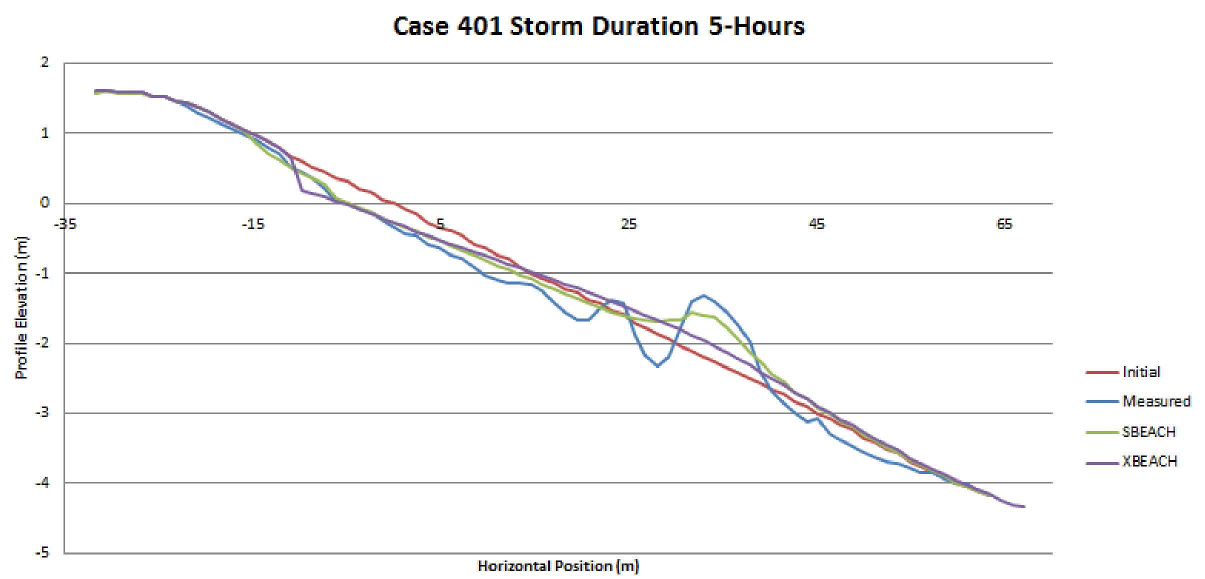
Case 500 Storm Duration 90-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Initial
Measured
SBEACH
XBEACH

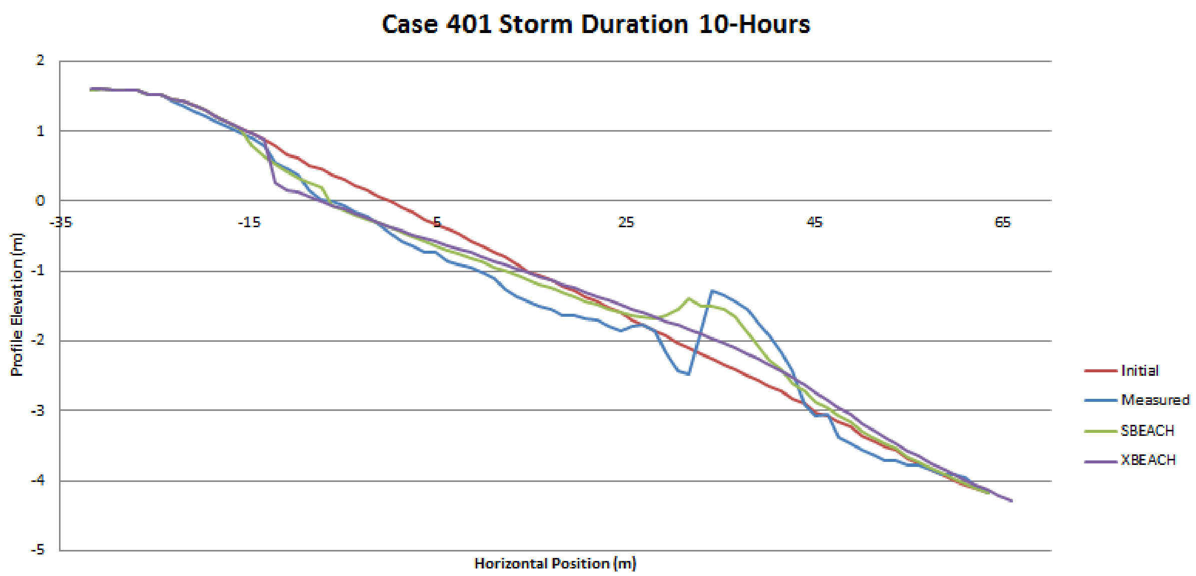


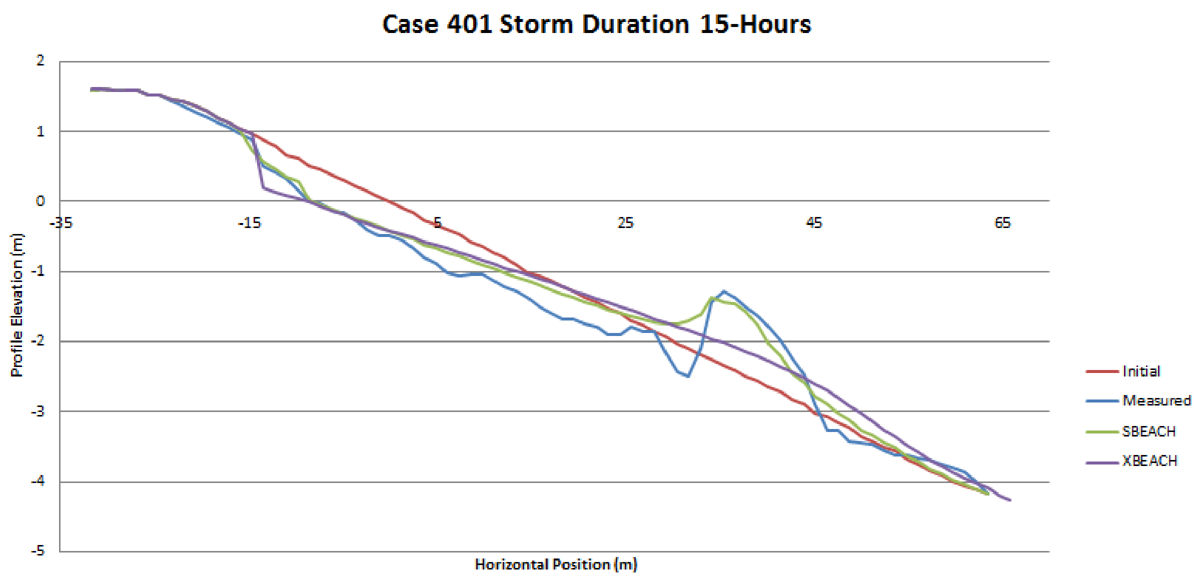
Case 500 Storm Duration 100-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-25
-5
15
35
55
75
Initial
Measured
SBEACH
XBEACH

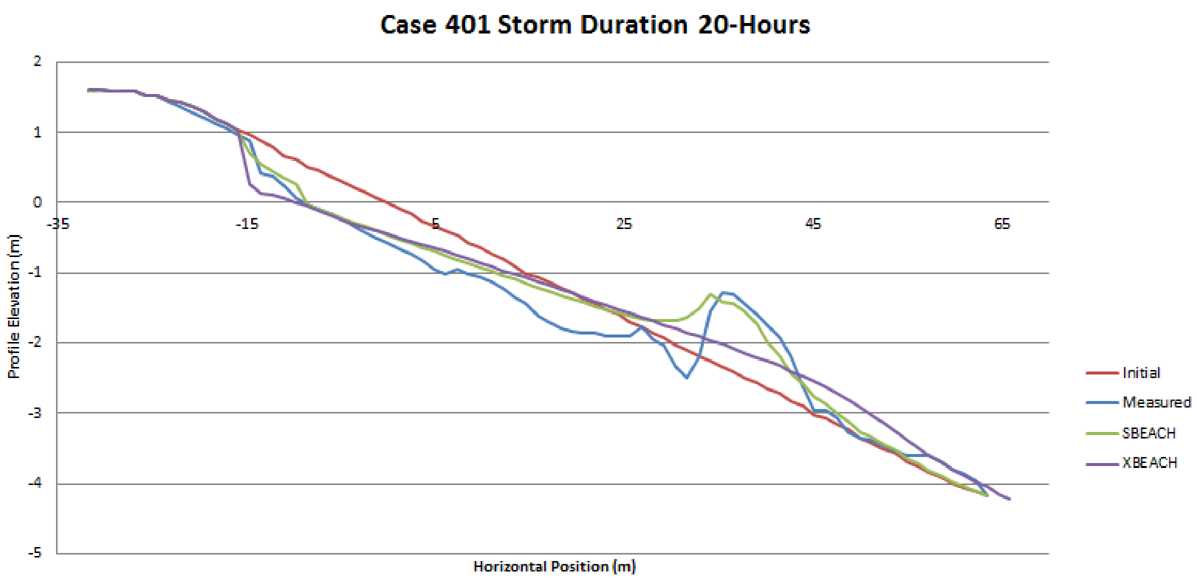

Case 401 Storm Duration 1-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

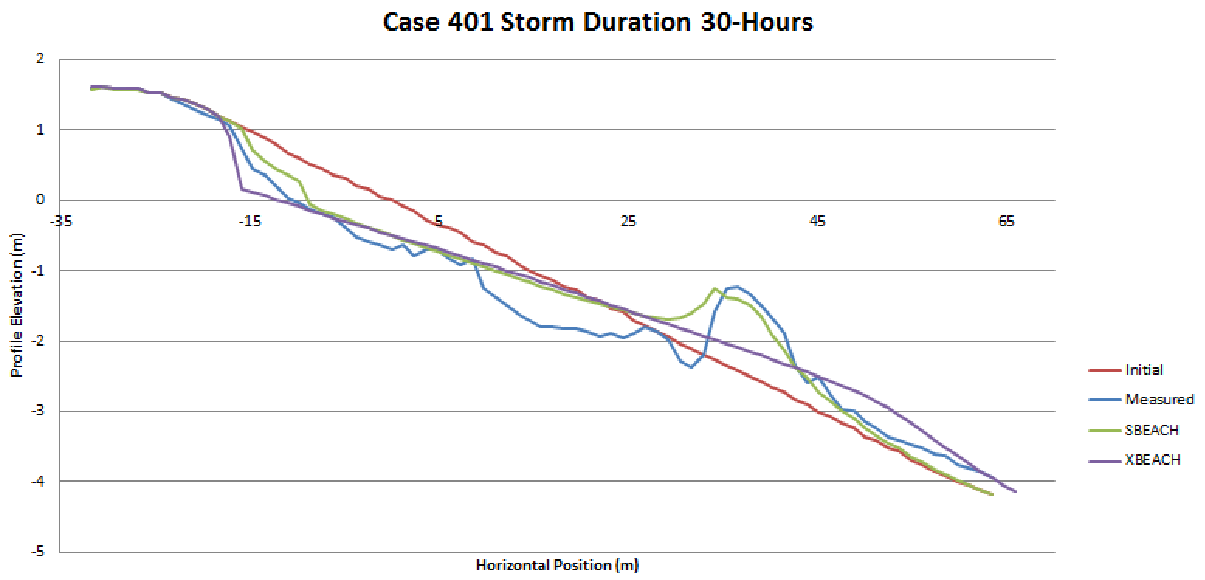

Case 401 Storm Duration 3-Hour
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

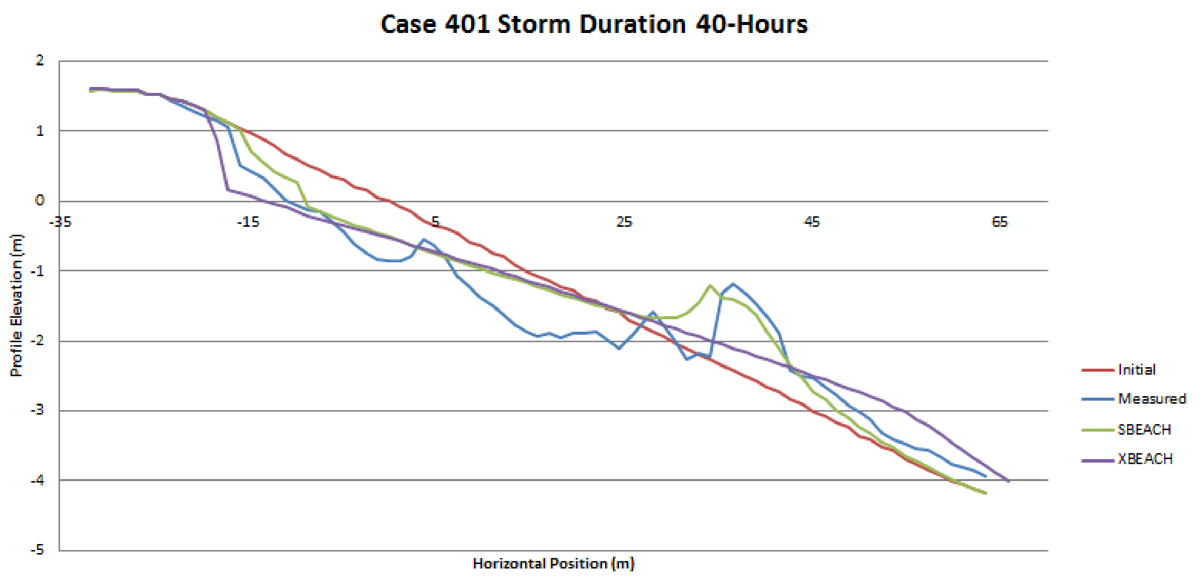

Case 401 Storm Duration 5-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

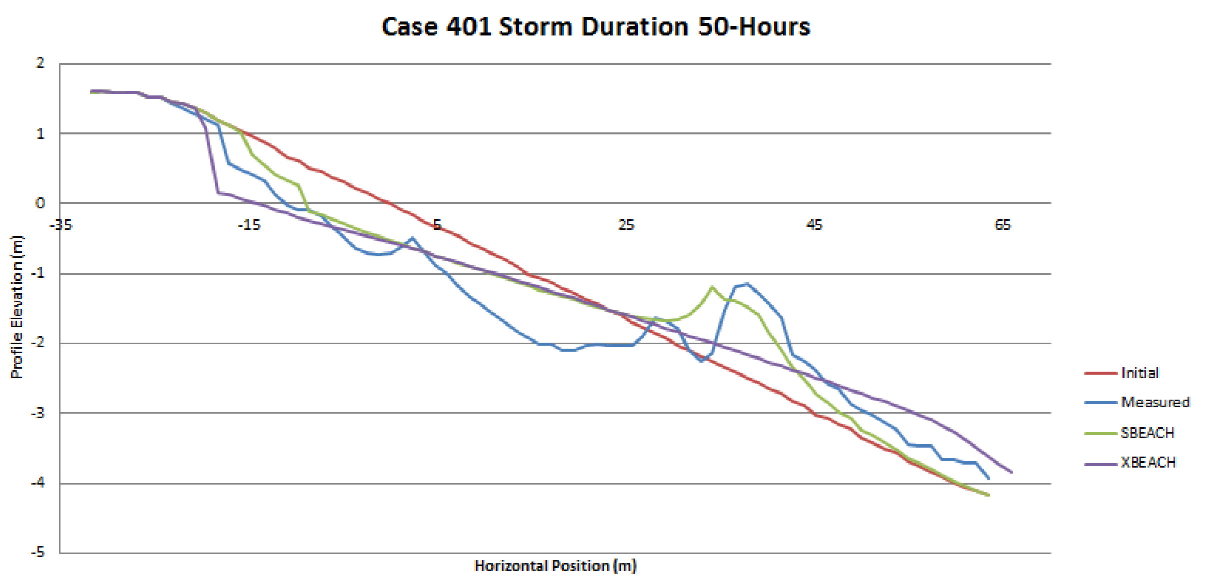

Case 401 Storm Duration 10-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

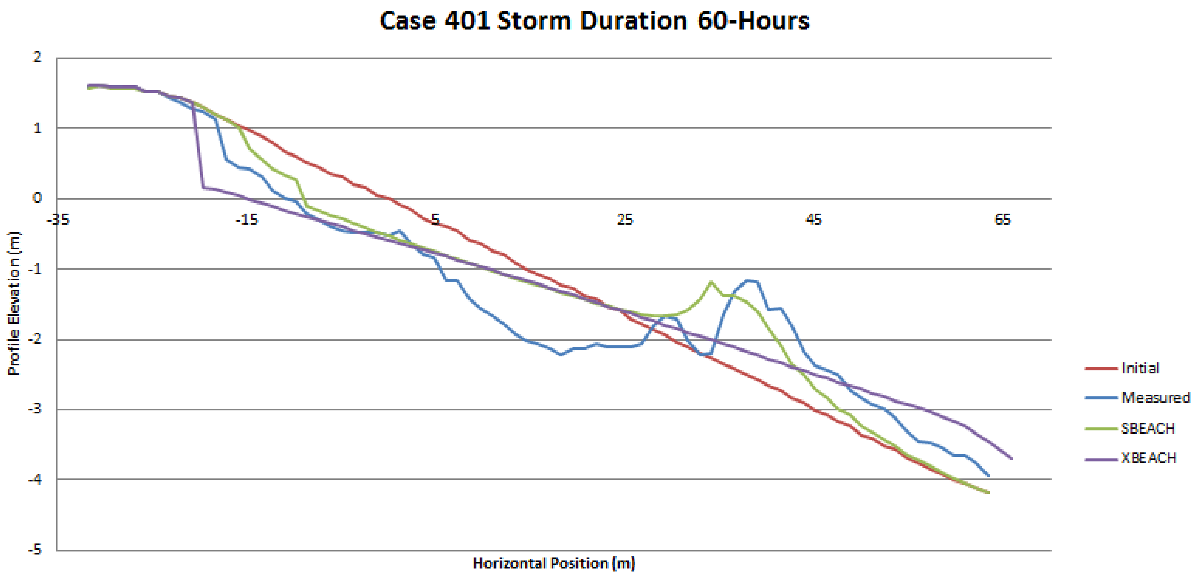

Case 401 Storm Duration 15-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

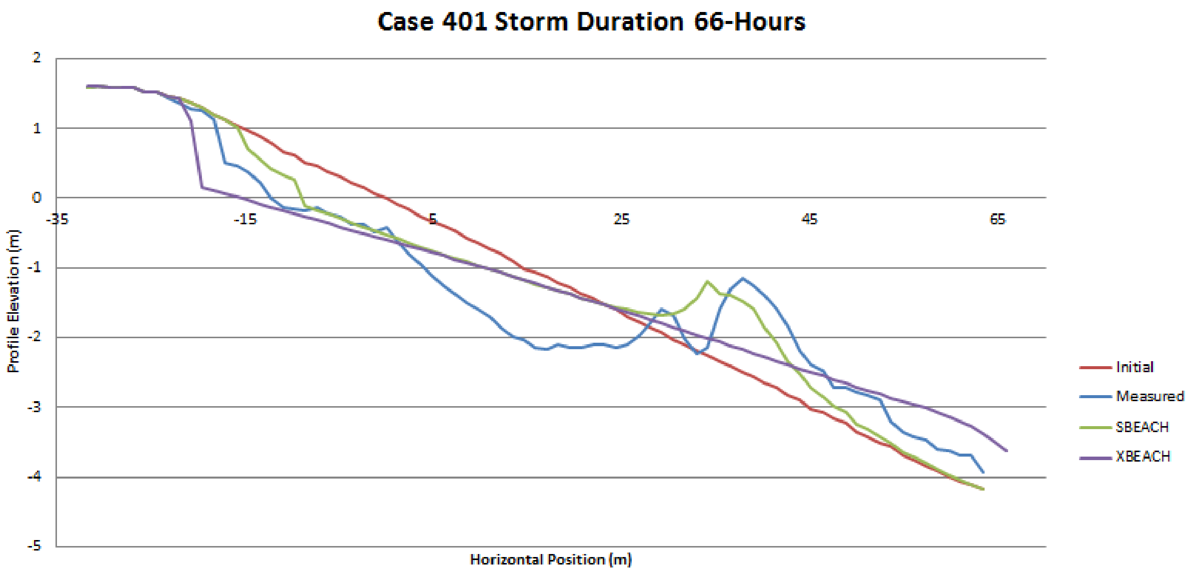

Case 401 Storm Duration 20-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

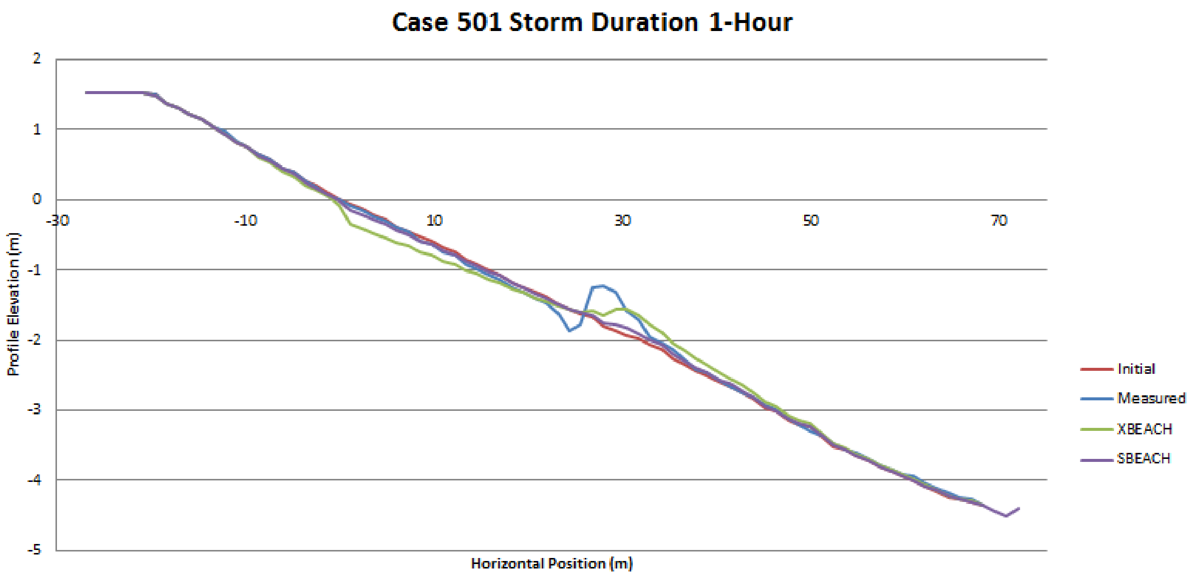

Case 401 Storm Duration 30-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

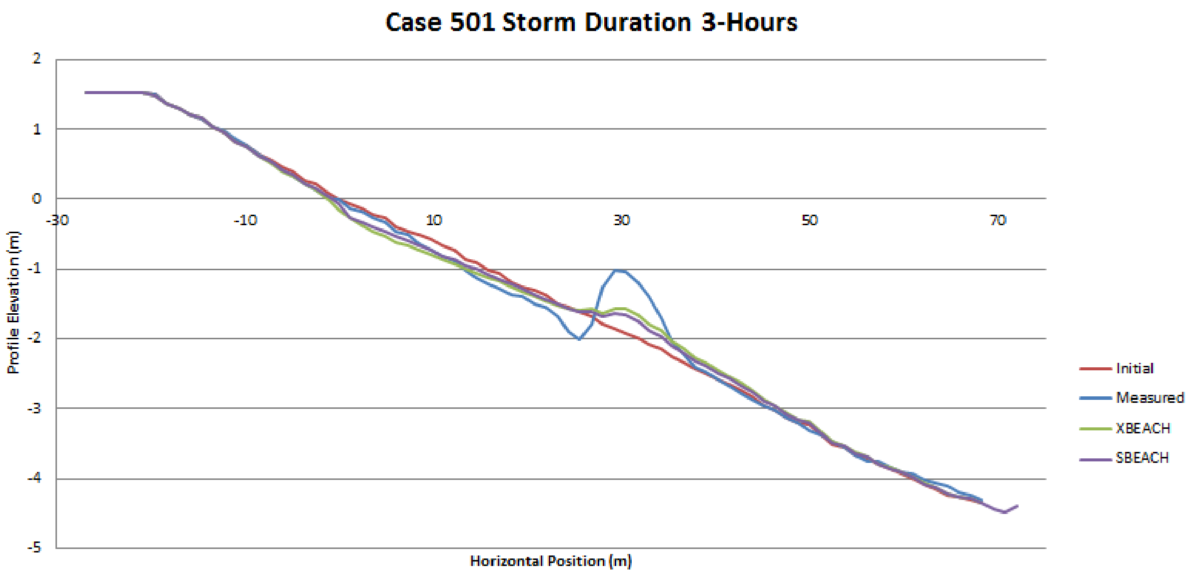

Case 401 Storm Duration 40-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

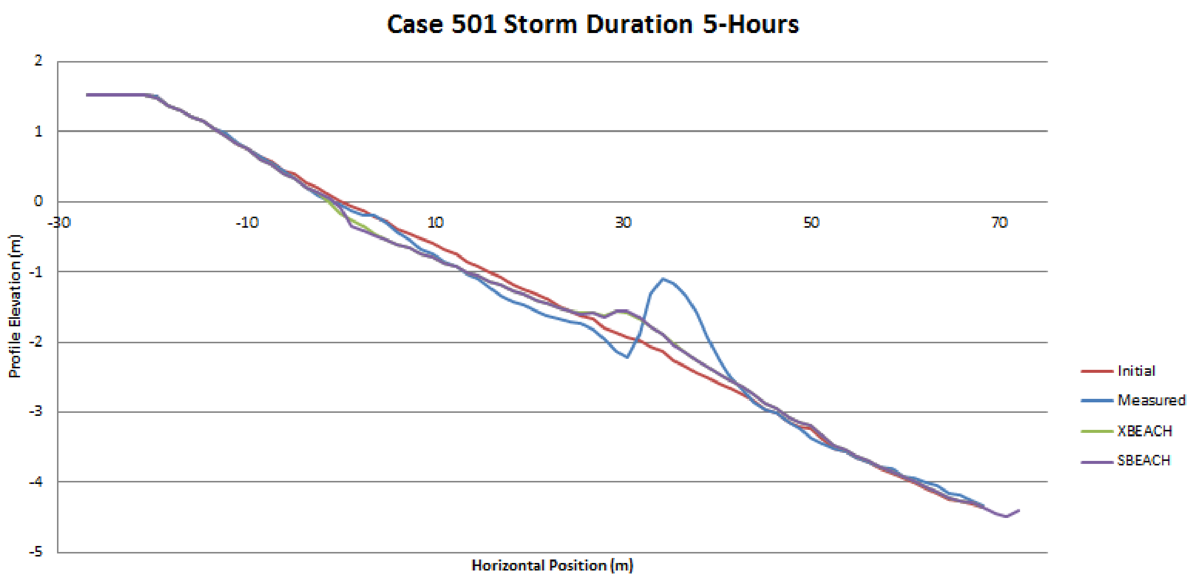

Case 401 Storm Duration 50-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH


Case 401 Storm Duration 60-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH

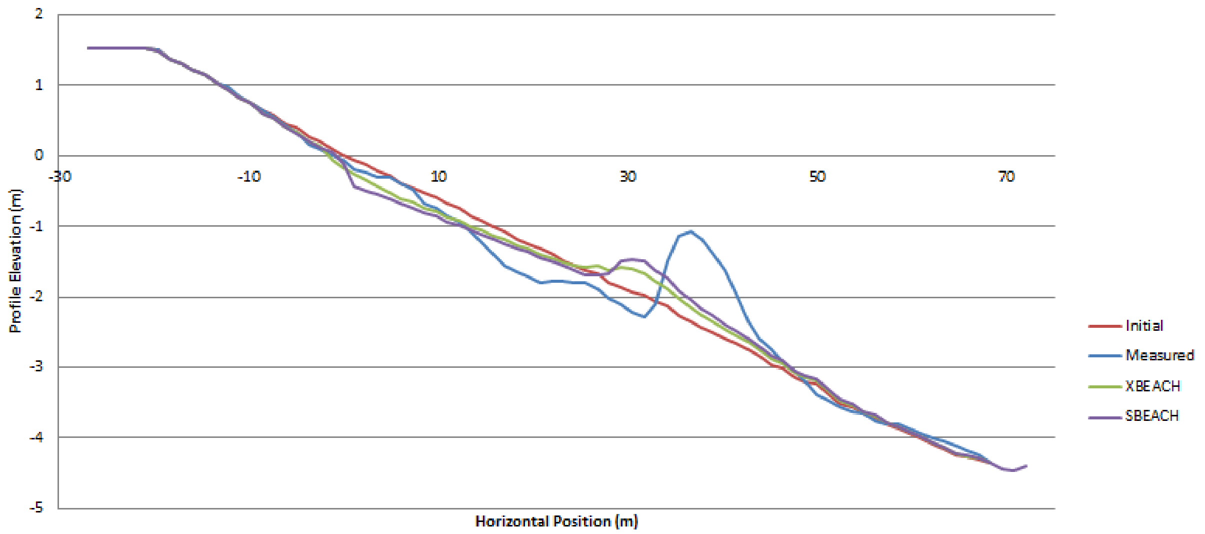

Case 401 Storm Duration 66-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-35
-15
5
25
45
65
Initial
Measured
SBEACH
XBEACH


Case 501 Storm Duration 1-Hour
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
XBEACH
SBEACH

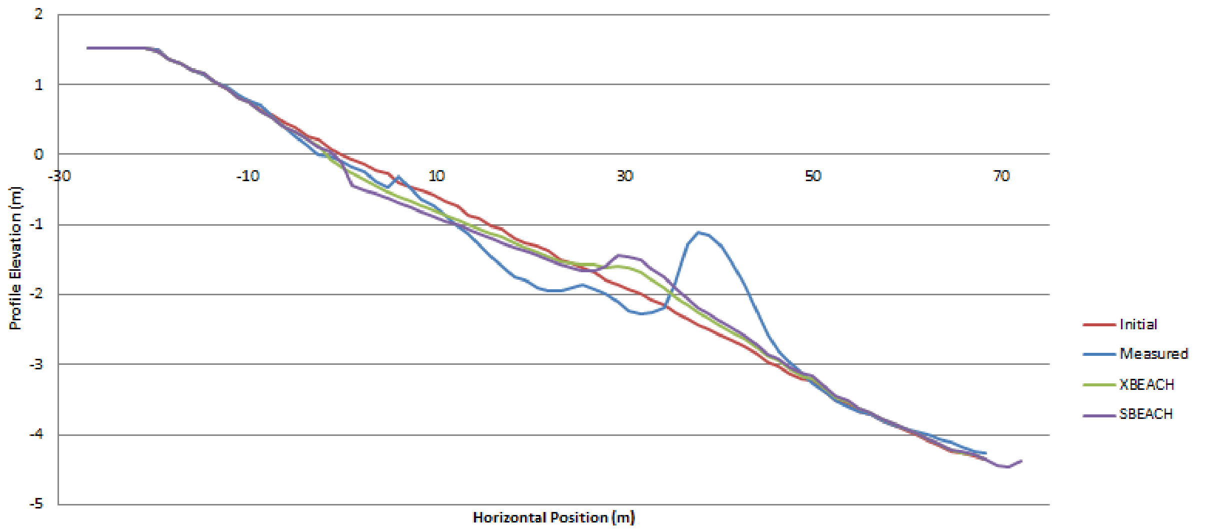

Case 501 Storm Duration 3-Hours
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
XBEACH
SBEACH


Case 501 Storm Duration 5-Hours
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Profile Elevation (m)
Horizontal Position (m)
Initial
Measured
XBEACH
SBEACH

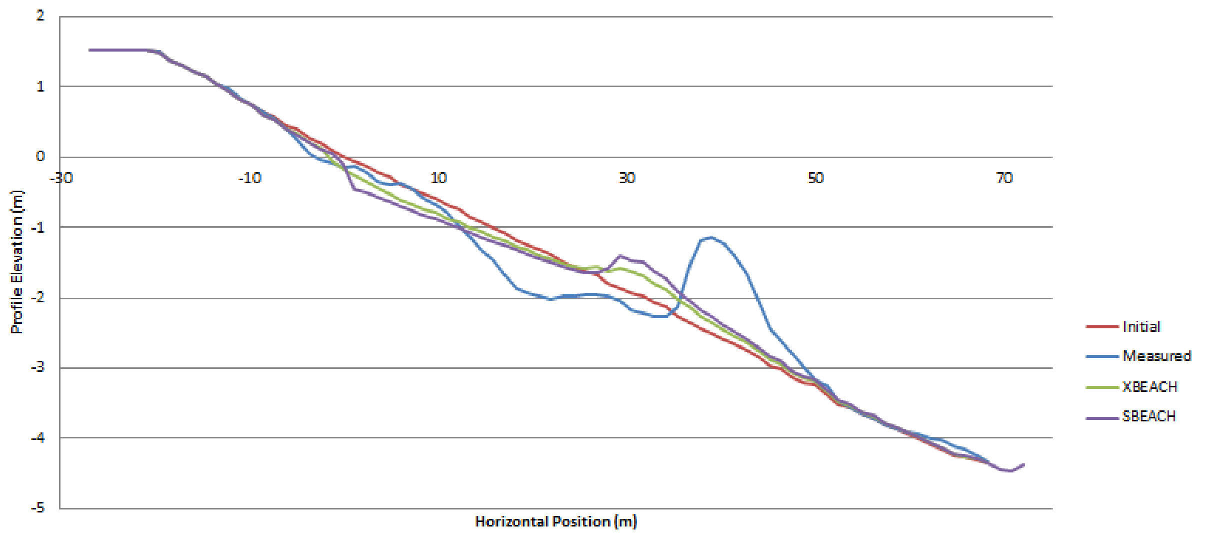
Case 501 Storm Duration 10-Hours

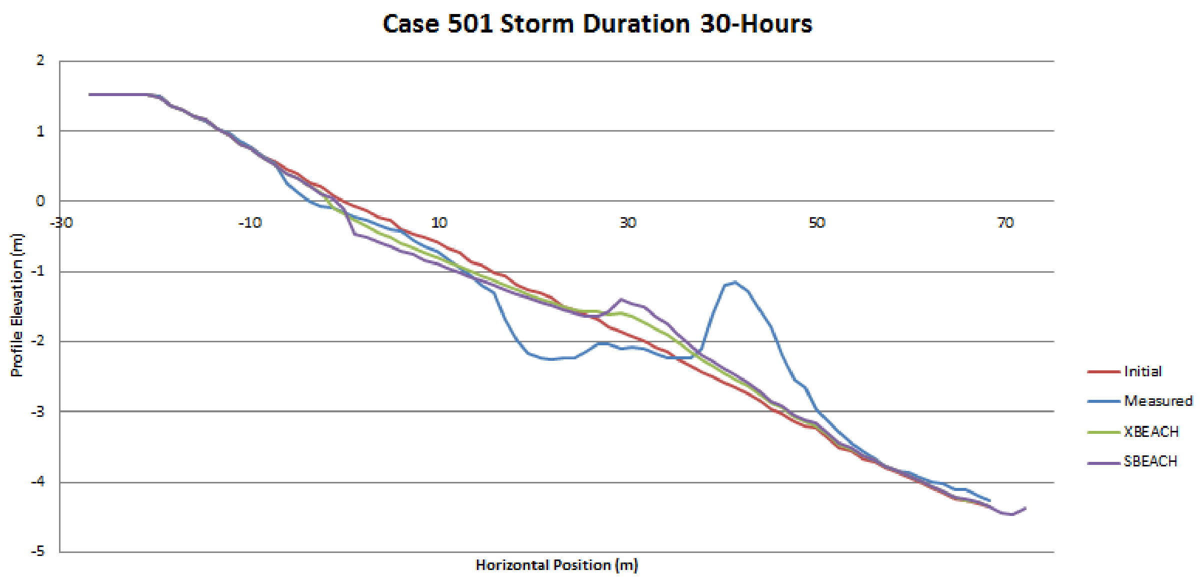


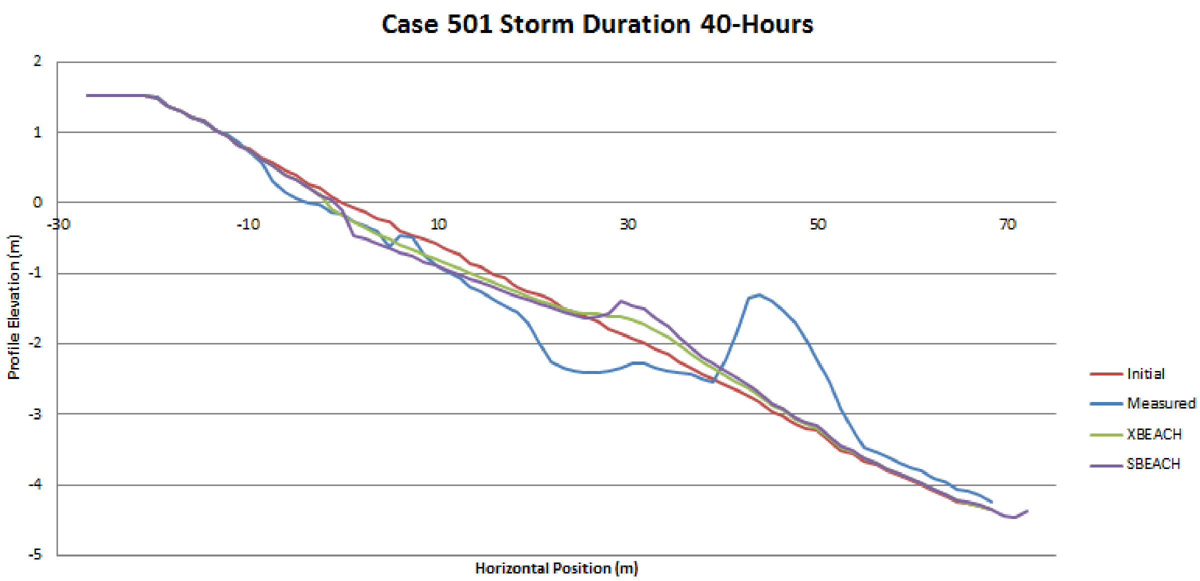
Case 501 Storm Duration 15-Hours

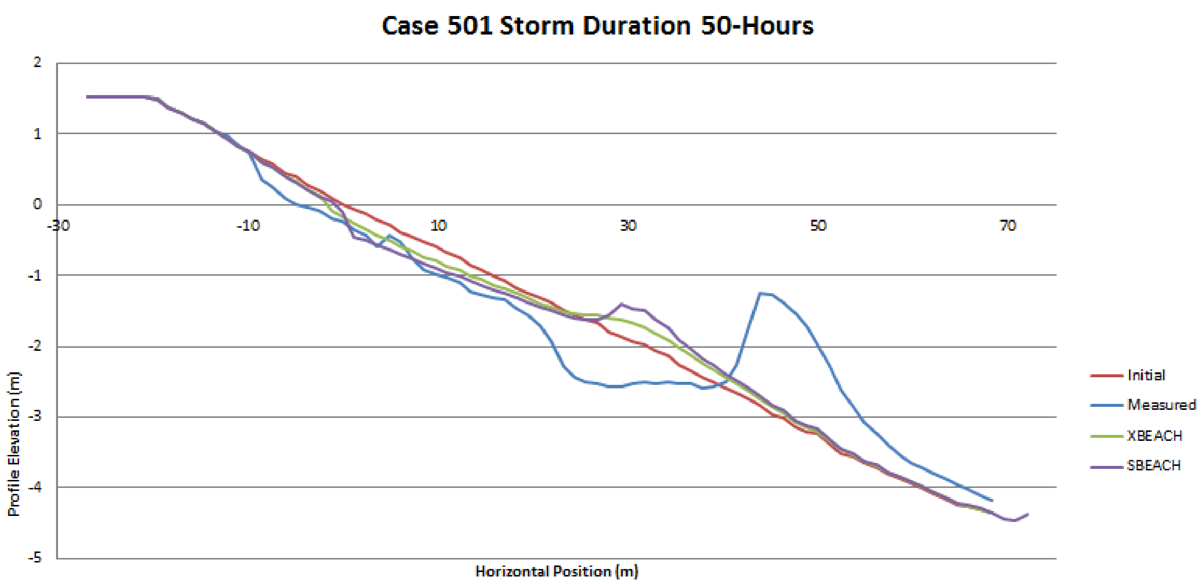


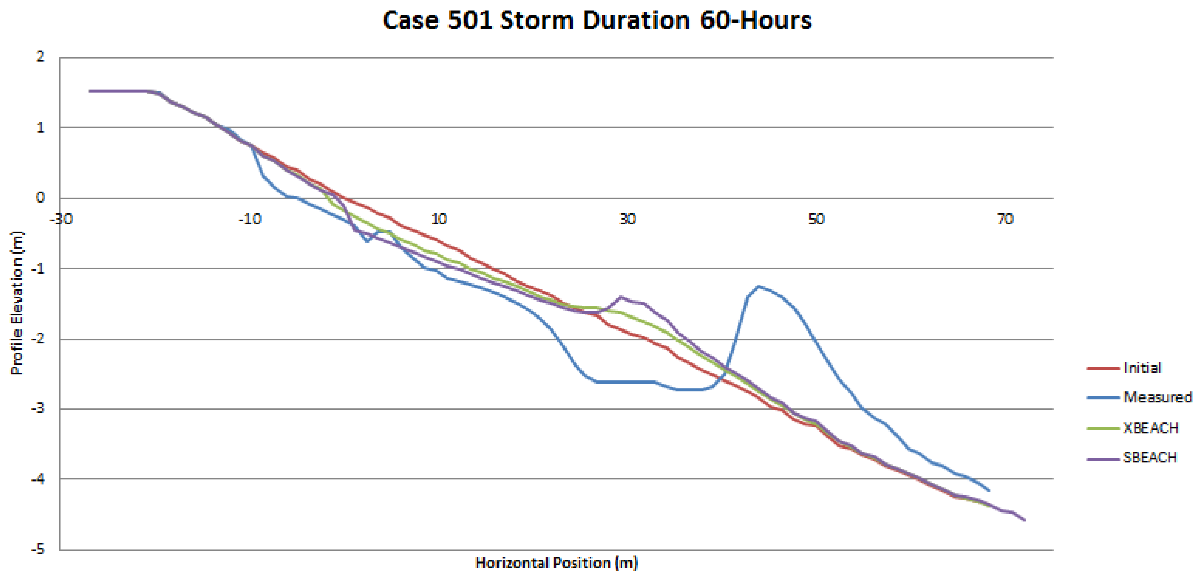
Case 501 Storm Duration 20-Hours




Case 501 Storm Duration 30-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
XBEACH
SBEACH


Case 501 Storm Duration 40-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
XBEACH
SBEACH


Case 501 Storm Duration 50-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
XBEACH
SBEACH



Case 501 Storm Duration 60-Hours
Profile Elevation (m)
Horizontal Position (m)
2
1
0
-1
-2
-3
-4
-5
-30
-10
10
30
50
70
Initial
Measured
XBEACH
SBEACH

DUNERULE INPUT

Case	sediment Size d50 (m)	(slope from waterline to 8m depth contour) Slope surf zone tanb (-)	Offshore wave height Hs,o (m)	Wave Period Tp (s)	Offshore wave angle to normal (pos. or neg.) Teta,o (deg.)	Tidal Flood level above mean sea level HWL (m)	Storm surge incl tide and wave setup above mean sea level SSL (m)	Dune height above MSL B (m)
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
300.00	0.000220	0.0667	1.7	11.3	0	1	1	1.92
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
400.00	0.000220	0.0667	1.6	5.6	0	1.13	1.13	1.646
500.00	0.000220	0.0667	1.5	3.8	0	0.61	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	0.69	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	0.77	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	0.85	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	0.93	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.01	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.09	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.17	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.25	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.33	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.41	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.49	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.57	0.69	1.494
500.00	0.000220	0.0667	1.5	3.8	0	1.65	0.69	1.494
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
401.00	0.000400	0.0667	1.6	5.6	0	0.97	0.97	1.585
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.524
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.5
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.5
501.00	0.000400	0.0667	1.5	3.8	0	0.3	0.3	1.5

DUNERULE OUTPUT

Dune Recession Van Rijn						
	erosion volume	mean recession	Maximum recession	erosion volume	mean recession	maximum recession
Time t (input value)	after 5 hours	after5 hours	after 5 hours	after t hours	after t hours	after t hours
(hours)	(m3/m)	(m)		(m3/m)	(m)	(m)
1	13.72507135	14.91855581	22.37783372	6.138038507	6.671780986	10.00767148
3	13.73	14.91855581	22.37783372	10.63139455	11.55586364	17.33379547
5	13.72507135	14.91855581	22.37783372	13.72507135	14.91855581	22.37783372
10	13.73	14.91855581	22.37783372	15.76596688	17.13692052	25.70538078
15	13.72507135	14.91855581	22.37783372	17.09774603	18.58450655	27.87675983
20	13.73	14.91855581	22.37783372	18.11034022	19.68515241	29.52772862
30	13.72507135	14.91855581	22.37783372	19.64015274	21.34799211	32.02198816
40	13.73	14.91855581	22.37783372	20.80331802	22.6123022	33.91845329
50	13.72507135	14.91855581	22.37783372	21.75277215	23.64431755	35.46647633
1	11.11	21.53	32.29	4.97	9.6	14.43959684
3	11.11	21.53	32.29	8.60	16.7	25.01011536
5	11.11	21.53	32.29	11.11	21.5	32.28792009
10	11.11	21.53	32.29	12.76	24.7	37.0890807
15	11.11	21.53	32.29	13.84	26.8	40.22206103
20	11.11	21.53	32.29	14.66	28.4	42.60416598
30	11.11	21.53	32.29	15.89	30.8	46.20301534
40	11.11	21.53	32.29	16.84	32.6	48.93933538
1	4.636457261	5.766737887	8.65010683	2.073486722	2.6	3.868445377
3	4.636457261	5.766737887	8.65010683	3.591384351	4.5	6.700343939
5	4.636457261	5.766737887	8.65010683	4.636457261	5.8	8.65010683
10	4.636457261	5.766737887	8.65010683	5.325890829	6.6	9.936363486
15	4.636457261	5.766737887	8.65010683	5.77577826	7.2	10.77570571
20	4.636457261	5.766737887	8.65010683	6.117842034	7.6	11.41388439
30	4.636457261	5.766737887	8.65010683	6.634626986	8.3	12.37803542
40	4.636457261	5.766737887	8.65010683	7.02755508	8.7	13.11111022
50	4.636457261	5.766737887	8.65010683	7.34828955	9.1	13.70949543
60	4.636457261	5.766737887	8.65010683	7.621185105	9.5	14.21862893
70	4.636457261	5.766737887	8.65010683	7.859806747	9.8	14.66381856
80	4.636457261	5.766737887	8.65010683	8.07254096	10.0	15.06071075
90	4.636457261	5.766737887	8.65010683	8.26496011	10.3	15.4197017
100	4.636457261	5.766737887	8.65010683	8.440968118	10.5	15.74807485
1	4.186694642	6.807633565	10.21145035	1.872346764	3.0	4.566699425
3	4.186694642	6.807633565	10.21145035	3.242999725	5.3	7.909755427
5	4.186694642	6.807633565	10.21145035	4.186694642	6.8	10.21145035
10	4.186694642	6.807633565	10.21145035	4.809249249	7.8	11.72987622
15	4.186694642	6.807633565	10.21145035	5.215495051	8.5	12.72071964
20	4.186694642	6.807633565	10.21145035	5.524376701	9.0	13.47408951
30	4.186694642	6.807633565	10.21145035	5.991030585	9.7	14.61226972
40	4.186694642	6.807633565	10.21145035	6.345842428	10.3	15.47766446
50	4.186694642	6.807633565	10.21145035	6.635463838	10.8	16.18405814
60	4.186694642	6.807633565	10.21145035	6.881886978	11.2	16.78509019
66	4.186694642	6.807633565	10.21145035	7.014328043	11.4	17.10811718
1	0.721791179	0.589698676	0.884548014	0.322794828	0.3	0.395581898
3	0.721791179	0.589698676	0.884548014	0.559097043	0.5	0.685167945
5	0.721791179	0.589698676	0.884548014	0.721791179	0.6	0.884548014
10	0.721791179	0.589698676	0.884548014	0.82912034	0.7	1.016078848
15	0.721791179	0.589698676	0.884548014	0.899157604	0.7	1.101908828
20	0.721791179	0.589698676	0.884548014	0.952409171	0.8	1.167168101
30	0.721791179	0.589698676	0.884548014	1.03286086	0.8	1.265760858
40	0.721791179	0.589698676	0.884548014	1.094030848	0.9	1.340724078
50	0.721791179	0.589698676	0.884548014	1.143961926	0.9	1.401914125
60	0.721791179	0.589698676	0.884548014	1.186445571	1.0	1.453977416

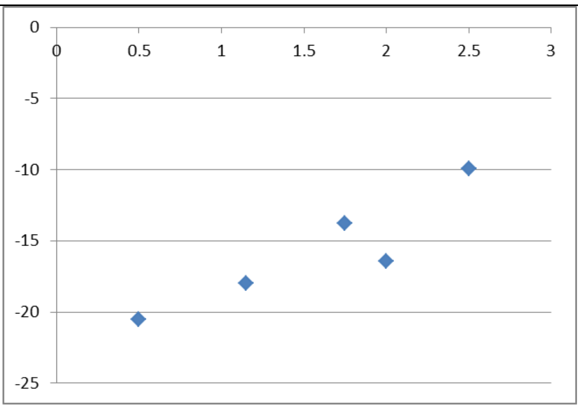
APPENDIX F: LONG WAVE ACCURACY

Appendix F-1: SBEACH Long Wave Accuracy Calibration

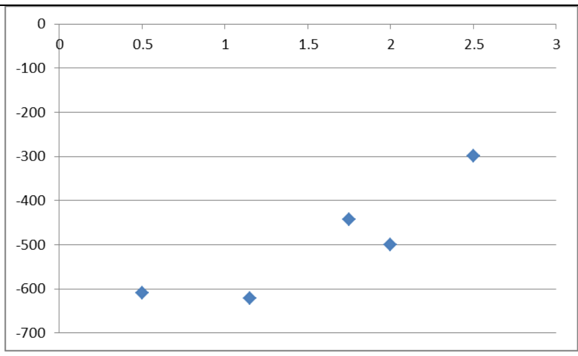
Run M_A

X: TRANSPORT RATE COEFFICIENT (m^4/N)

Y: BSS

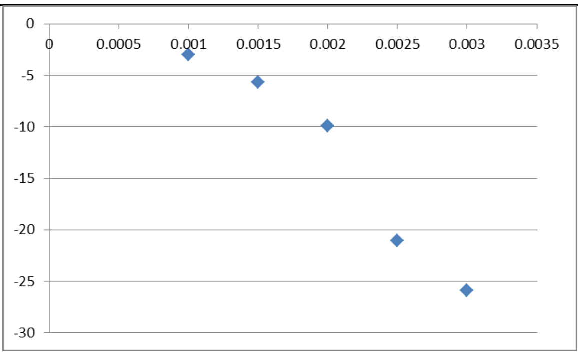


Y: Eroded Volume %

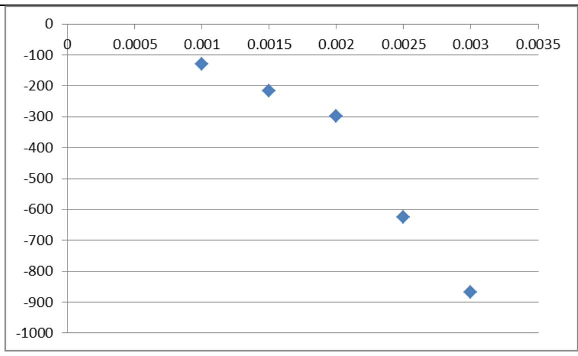


X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS

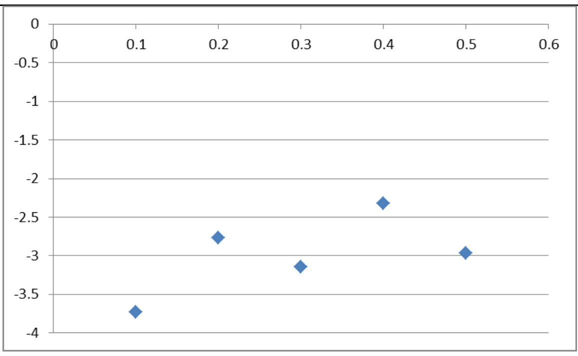


Y: Eroded Volume %

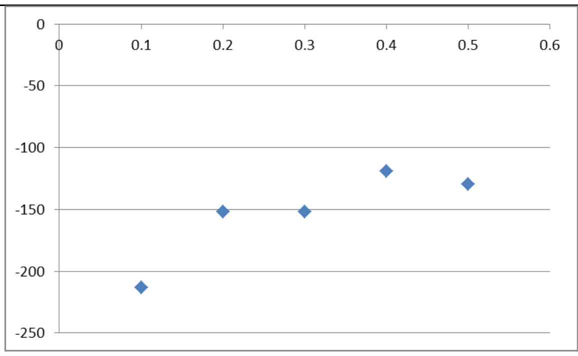


X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

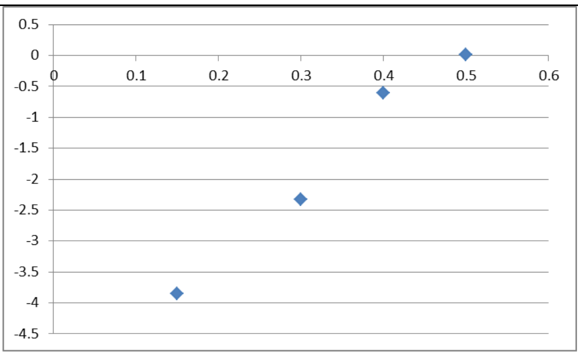
Y: BSS



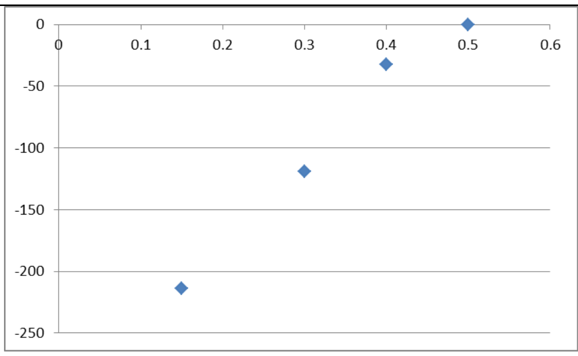
Y: Eroded Volume %



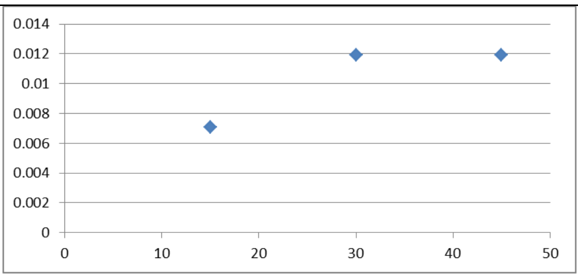
<table>
<tr><th colspan="2">X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>



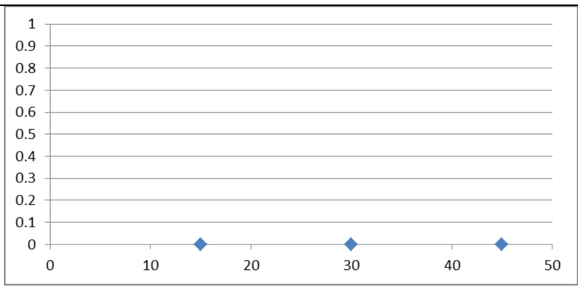
</td><td>



</td></tr>
<tr><th colspan="2">X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>



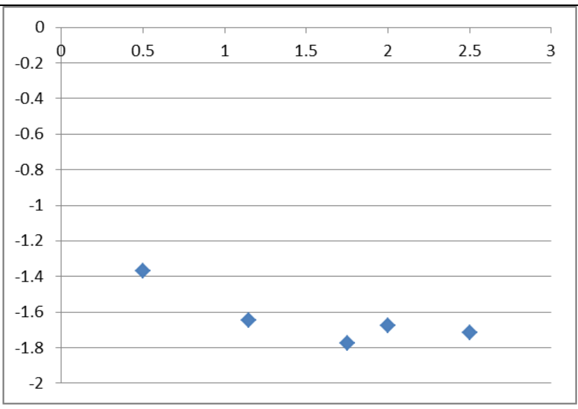
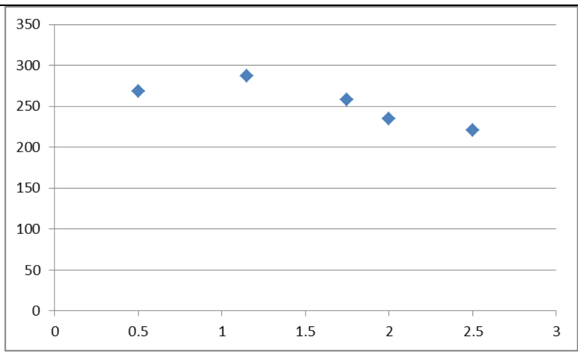
</td><td>



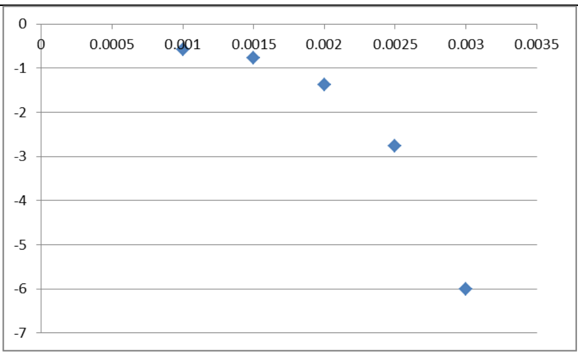
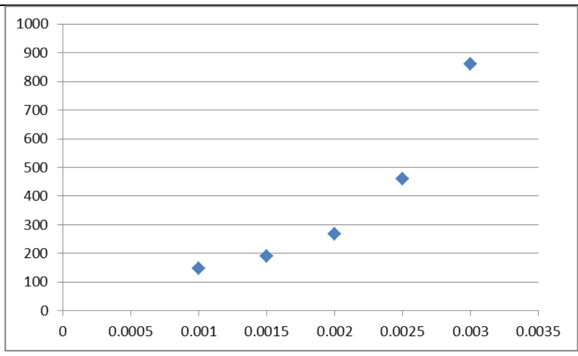
</td></tr>
</table>

Run M_E

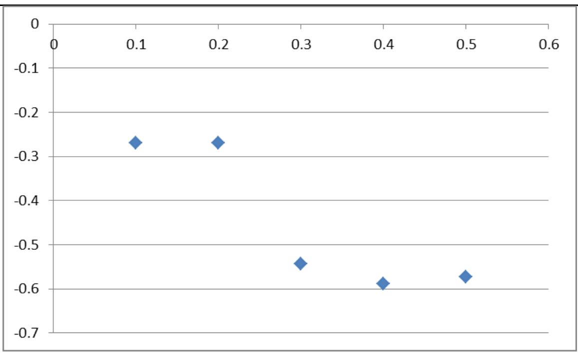
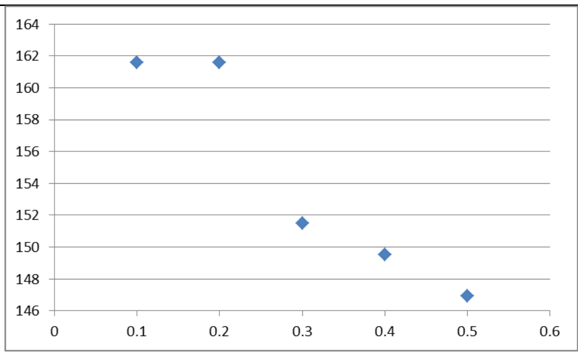
X: TRANSPORT RATE COEFFICIENT (m^4/N)

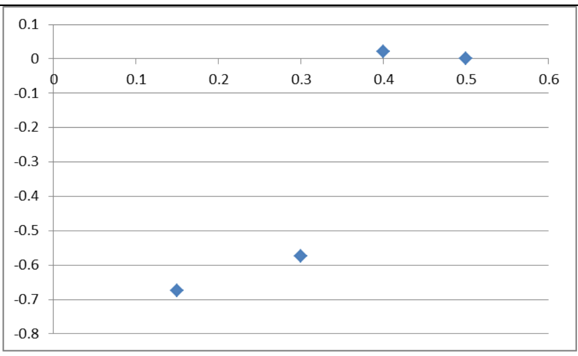
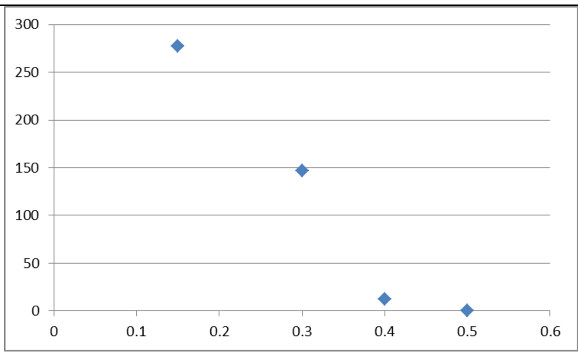
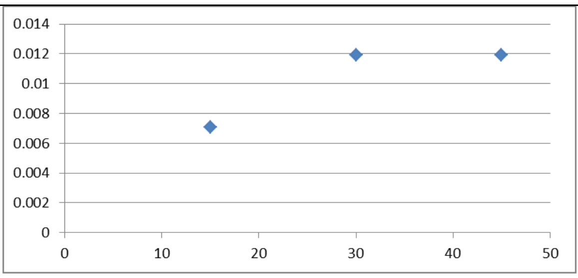
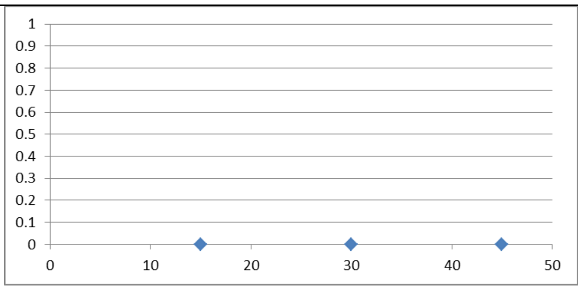
Y: BSS	Y: Eroded Volume %
	

X: COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s)

Y: BSS	Y: Eroded Volume %
	

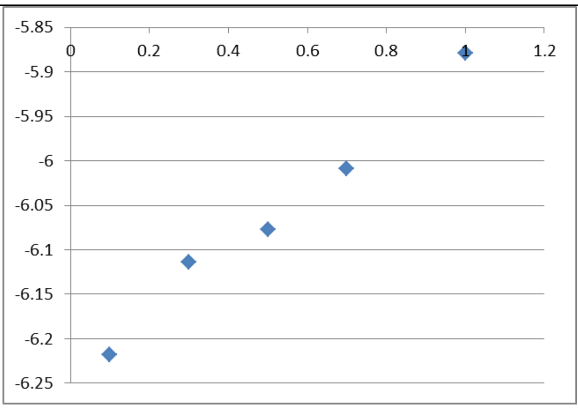
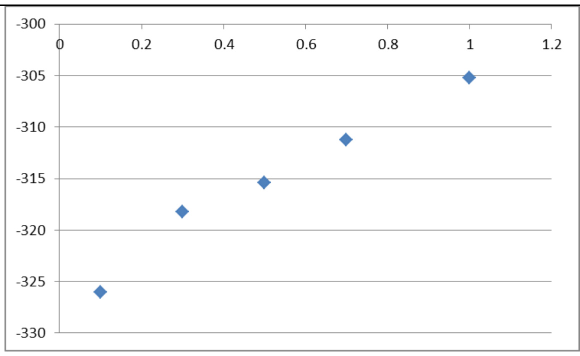
X: TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER

Y: BSS	Y: Eroded Volume %
	

<table>
<tr><th colspan="2">X: DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE (m)</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">X: MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Appendix F-2: XBEACH Long Wave Accuracy Calibration

Run M_A

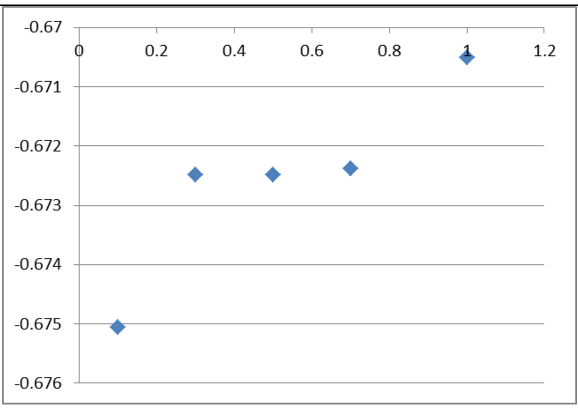
<table>
<tr><th colspan="2">X: Wetslp</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

*Further calibration was not done, since the results were even less accurate than the M_E results which could not be calibrated properly.

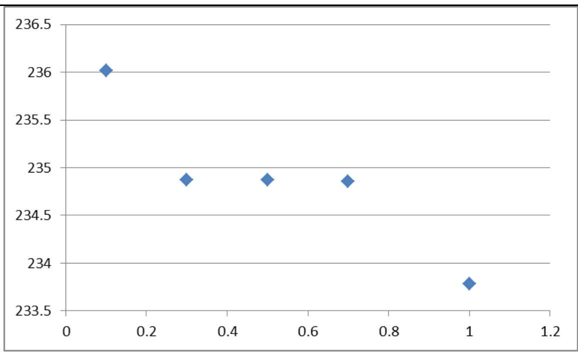
Run M_E

X: Wetslp

Y: BSS

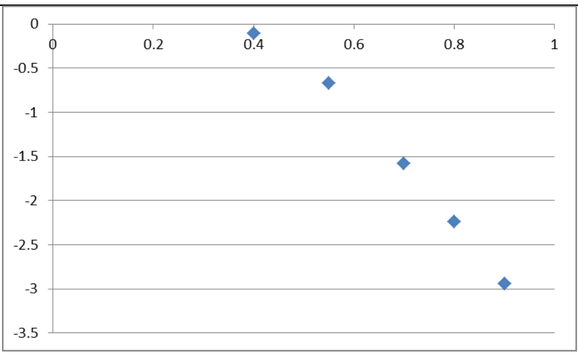


Y: Eroded Volume %

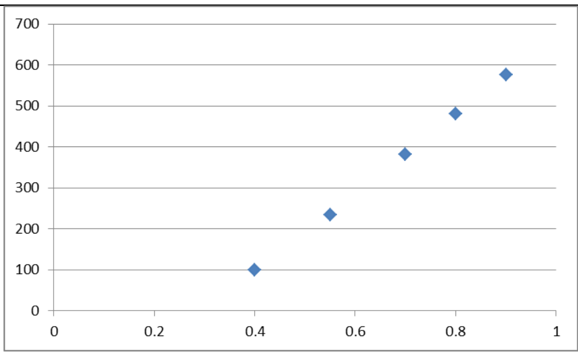


X: Gamma

Y: BSS

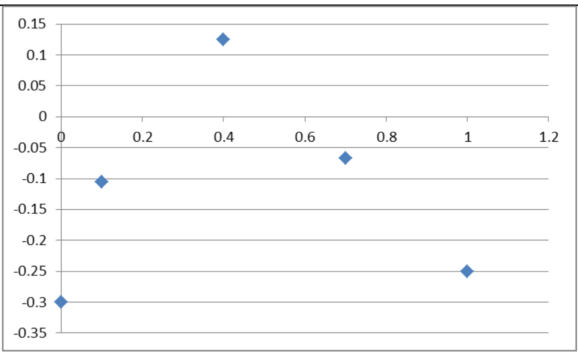


Y: Eroded Volume %

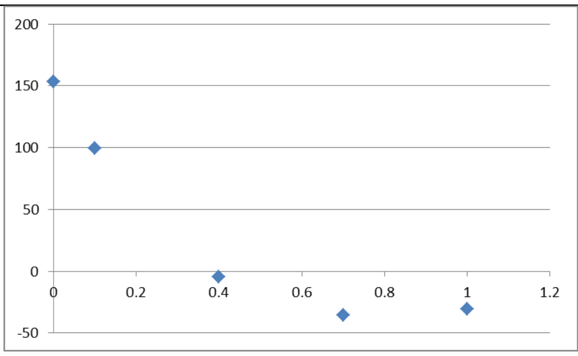


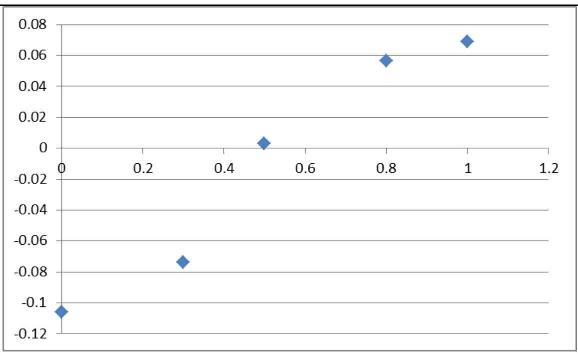
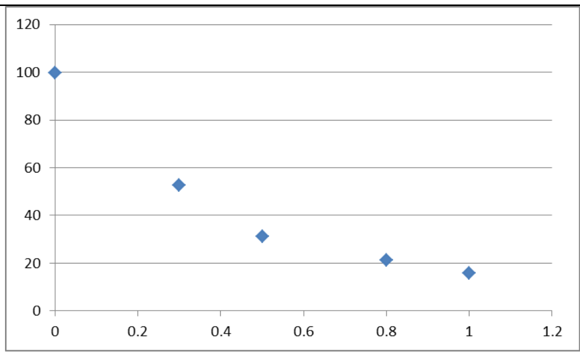
X: Facua

Y: BSS



Y: Eroded Volume %



<table>
<tr><th colspan="2">X: Fw</th></tr>
<tr><th>Y: BSS</th><th>Y: Eroded Volume %</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Appendix F-3: Model Configuration/Parameter Setups for Free Long Wave Accuracy

****

* SBEACH model configuration file: C_E4.CFG *

****

A--------------------------- MODEL SETUP -------------------------------A

A.1 RUN TITLE: TITLE

C_E4: Free long waves, erosional monochromatic conditions

A.2 INPUT UNITS (SI=1, AMERICAN CUST.=2): UNITS

1

A.3 TOTAL NUMBER OF CALCULATION CELLS AND POSITION OF LANDWARD BOUNDARY

RELATIVE TO INITIAL PROFILE: NDX, XSTART

569 -9.11

A.4 GRID TYPE (CONSTANT=0, VARIABLE=1): IDX

0

A.5 COMMENT: IF GRID TYPE IS VARIABLE, CONTINUE TO A.8

A.6 CONSTANT GRID CELL WIDTH: DXC

0.1

A.7 COMMENT: IF GRID TYPE IS CONSTANT CONTINUE TO A.10

A.8 NUMBER OF DIFFERENT GRID CELL REGIONS: NGRID

3

A.9 GRID CELL WIDTHS AND NUMBER OF CELLS IN EACH REGION FROM LANDWARD

TO SEAWARD BOUNDARY: (DXV(I), NDXV(I), I=1,NGRID)

0.3,10 0.1,250 0.75,38

A.10 NUMBER OF TIME STEPS AND VALUE OF TIME STEP IN MINUTES: NDT,DT

8280 0.0166667

A.11 NUMBER OF TIME STEP(S) INTERMEDIATE OUTPUT IS WANTED: NWR

3

A.12 TIME STEPS OF INTERMEDIATE OUTPUT: (WRI(I), I=1,NWR)

23 46 92

A.13 IS A MEASURED PROFILE AVAILABLE FOR COMPARISON? (NO=0, YES=1): ICOMP

1

A.14 THREE PROFILE ELEVATION CONTOURS (MAXIMUM HORIZONTAL RECESSION OF EACH WILL BE DETERMINED): ELV1, ELV2, ELV3

0.2 0.1 0.00

A.15 THREE PROFILE EROSION DEPTHS AND REFERENCE ELEVATION (DISTANCE FROM POSITION OF REFERENCE ELEVATION ON INITIAL PROFILE TO POSITION OF LANDWARD MOST OCCURENCE OF EACH EROSION DEPTH WILL BE DETERMINED EDP1, EDP2, EDP3, REFELV

0.2 0.1 0.00 0.00

A.16 TRANSPORT RATE COEFFICIENT (m^4/N): K

1.75E-6

A.17 COEFFICIENT FOR SLOPE-DEPENDENT TERM (m^2/s): EPS

0.002000

A.18 TRANSPORT RATE DECAY COEFFICIENT MULTIPLIER: LAMM

0.500000

A.19 WATER TEMPERATURE IN DEGREES C: TEMPC

15

B---------------------- WAVES/WATER ELEVATION/WIND ----------------------B

B.1 WAVE TYPE (MONOCHROMATIC=1, IRREGULAR=2): WVTYPE

1

B.2 WAVE HEIGHT AND PERIOD INPUT (CONSTANT=0, VARIABLE=1): IWAVE

0

B.3 COMMENT: IF WAVE HEIGHT AND PERIOD ARE VARIABLE, CONTINUE TO B.6

B.4 CONSTANT WAVE HEIGHT AND PERIOD: HIN, T

0.37   3.7

B.5 COMMENT: IF WAVE HEIGHT AND PERIOD ARE CONSTANT, CONTINUE TO B.7

B.6 TIME STEP OF VARIABLE WAVE HEIGHT AND PERIOD INPUT IN MINUTES: DTWAV

60.00

B.7 WAVE ANGLE INPUT (CONSTANT=0, VARIABLE=1): IANG

0

B.8 COMMENT: IF WAVE ANGLE IS VARIABLE, CONTINUE TO B.11

B.9 CONSTANT WAVE ANGLE: ZIN

0.00

B.10 COMMENT: IF WAVE ANGLE IS CONSTANT, CONTINUE TO B.12

B.11 TIME STEP OF VARIABLE WAVE ANGLE INPUT IN MINUTES: DTANG

0.00

B.12 WATER DEPTH OF INPUT WAVES (DEEPWATER=0): DMEAS

0

B.13 IS RANDOMIZATION OF WAVE HEIGHT DESIRED? (NO=0, YES=1): IRAND

0

B.14 COMMENT: IF RANDOMIZATION OF WAVE HEIGHT IS NOT DESIRED, CONTINUE TO B.16

B.15 SEED VALUE FOR RANDOMIZER AND PERCENT OF VARIABILITY: ISEED, RPERC

7878   20.00

B.16 TOTAL WATER ELEVATION INPUT (CONSTANT=0, VARIABLE=1): IELEV

1

B.17 COMMENT: IF WATER ELEVATION IS VARIABLE CONTINUE TO B.20

B.18 CONSTANT TOTAL WATER ELEVATION: TELEV

0

B.19 COMMENT: IF WATER ELEVATION IS CONSTANT, CONTINUE TO B.21

B.20 TIME STEP OF VARIABLE TOTAL WATER ELEVATION INPUT IN MINUTES: DTELV

0.016667

B.21 WIND SPEED AND ANGLE INPUT (CONSTANT=0, VARIABLE=1): IWIND

0

B.22 COMMENT: IF WIND SPEED AND ANGLE ARE VARIABLE, CONTINUE TO B.25

B.23 CONSTANT WIND SPEED AND ANGLE: W,ZWIND

0.00 0.00

B.24 COMMENT: IF WIND SPEED AND ANGLE ARE CONSTANT, CONTINUE TO C.

B.25 TIME STEP OF VARIABLE WIND SPEED AND ANGLE INPUT IN MINUTES: DTWND

0.00

C------------------------------ BEACH ----------------------------------C

C.1 TYPE OF INPUT PROFILE (ARBITRARY=1, SCHEMATIZED=2): TPIN

1

C.2 COMMENT: IF PROFILE TYPE IS ARBITRARY CONTINUE TO C.4

C.3 LOCATION AND ELEVATION OF LANDWARD BOUNDARY, LANDWARD BASE OF DUNE,
LANDWARD CREST OF DUNE, SEAWARD CREST OF DUNE, START OF BERM,
END OF BERM, AND FORESHORE: XLAND,DLAND,XLBDUNE,DLBDUNE,XLCDUNE,DLCDUNE,
XSCDUNE,DSCDUNE,XBERMS,DBERMS,XBERME,DBERME,XFORS,DFORS

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

C.4 DEPTH CORRESPONDING TO LANDWARD END OF SURF ZONE: DFS

0.30

C.5 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50

0.25

C.6 MAXIMUM PROFILE SLOPE PRIOR TO AVALANCHING IN DEGREES: BMAX

30.00

D------------------------------ BEACH FILL ---------------------------------D

D.1 IS A BEACH FILL PRESENT? (NO=0, YES=1): IBCHFILL

0

D.2 COMMENT: IF NO BEACH FILL, CONTINUE TO E.

D.3 POSITION OF START AND END OF BEACH FILL RELATIVE

TO INITIAL PROFILE: XBFS, XBFE

0.00 0.00

D.4 NUMBER OF REPRESENTATIVE POINTS BETWEEN START

AND END OF BEACH FILL: NFILL

0

D.5 LOCATION AND ELEVATION OF REPRESENTATIVE POINTS RELATIVE TO THE

INITIAL PROFILE: (XF(I), EFILL(I), I=1,NFILL)

E--------------------------- SEAWALL/REVETMENT ----------------------------E

E.1 IS A SEAWALL PRESENT? (NO=0, YES=1): ISWALL

0

E.2 COMMENT: IF NO SEAWALL, CONTINUE TO F.

E.3 LOCATION OF SEAWALL RELATIVE TO INITIAL PROFILE: XSWALL

0.00

E.4 IS SEAWALL ALLOWED TO FAIL? (NO=0, YES =1): ISWFAIL

0

E.5 COMMENT: IF NO SEAWALL FAILURE, CONTINUE TO F.

E.6 PROFILE ELEVATION AT SEAWALL WHICH CAUSES FAILURE, TOTAL WATER ELEVATION

AT SEAWALL WHICH CAUSES FAILURE, AND WAVE HEIGHT AT SEAWALL WHICH CAUSES

FAILURE: PEFAIL, WEFAIL,HFAIL

0.00 0.00 0.00

F------------------------------ COMMENTS --------------------------------F

----------------------------------- END ------------------------------------

```
%%% XBeach parameter settings input file %%%
%%% %%%
%%% date: 30-aug-2016 12:00 %%%
%%% function: xb_write_params %%%
%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%xbeach/delft3d
gridform = xbeach
depfile = DepSeaLevel.dep
posdwn = -1
alfa = 0
dx = 0.1
dy = 0
nx = 568
ny = 0
%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
thetamin = -90
thetamax = +90
dtheta = 10
thetanaut = 0
 %%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tstart = 0
tstop = 8280
tintg = 60
tintp = 60
 %%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 rho = 1025
g = 9.81
D50 = 0.00025
D90 = 0.000372
rhos = 2650
por = 0.3
 %%% Flow boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

front = abs_1d

back = abs_1d

left = 0

right = 0

%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tideloc = 1

zs0file = tide.txt

%%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

instat = 0

Hrms = 0.37

Trep = 3.7

%%% Morphology Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

morstart = 0

%%% Output variables %%%

outputformat = netcdf

nglobalvar = 6

zb

zb0

zs

H

hh

Qb

nmeanvar = 3

H

hh

zs

Appendix F-4: Model Configuration/Parameter Setups for Bound Long Waves

```
%%% XBeach parameter settings input file %%%
%%% date: 30-Aug-2016 12:00 %%%
%%% function: xb_write_params %%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%xbeach/delft3d
gridform = xbeach
depfile = DepSeaLevel.dep
posdwn = -1
alfa = 0
dx = 0.1
dy = 0
nx = 568
ny = 0

%%% Spectral Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

thetamin = -90
thetamax = +90
dtheta = 10
thetanaut = 0

%%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tstart = 0
tstop = 8280
tintg = 60
tintp = 60

%%% Physical constants & Sediment %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rho = 1025
g = 9.81
D50 = 0.00025
D90 = 0.000372
rhos = 2650
por = 0.3

%%% Flow boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

front = abs_1d
back = abs_1d
```

left = 0
right = 0

%%% Tide boundary conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tideloc = 0
zs0 = 0

%%% Wave boundary Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

instat = 1
Hrms = 0.16
Trep = 4.73
Tlong = 15

%%% Morphology Conditions %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

morstart = 0

%%% Output variables %%

outputformat = netcdf

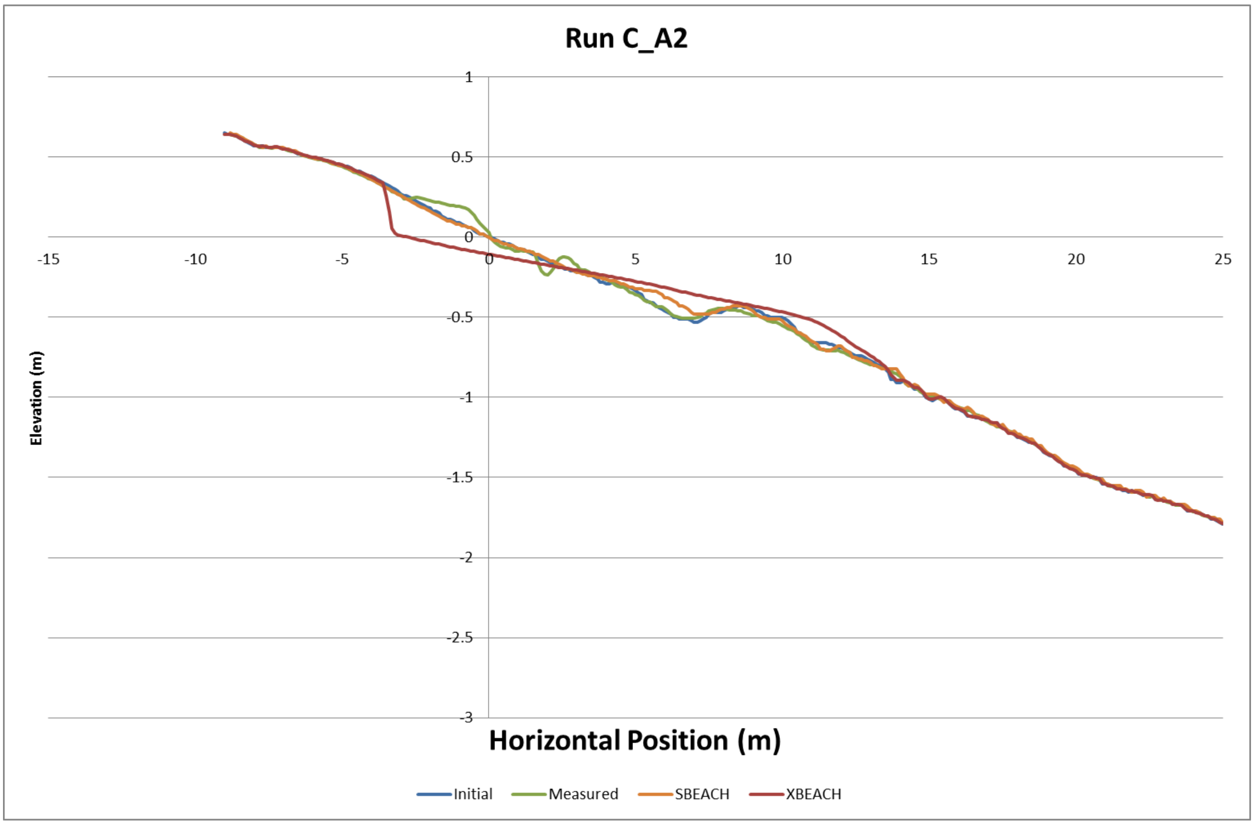
nglobalvar = 6
zb
zb0
zs
H
hh
Qb

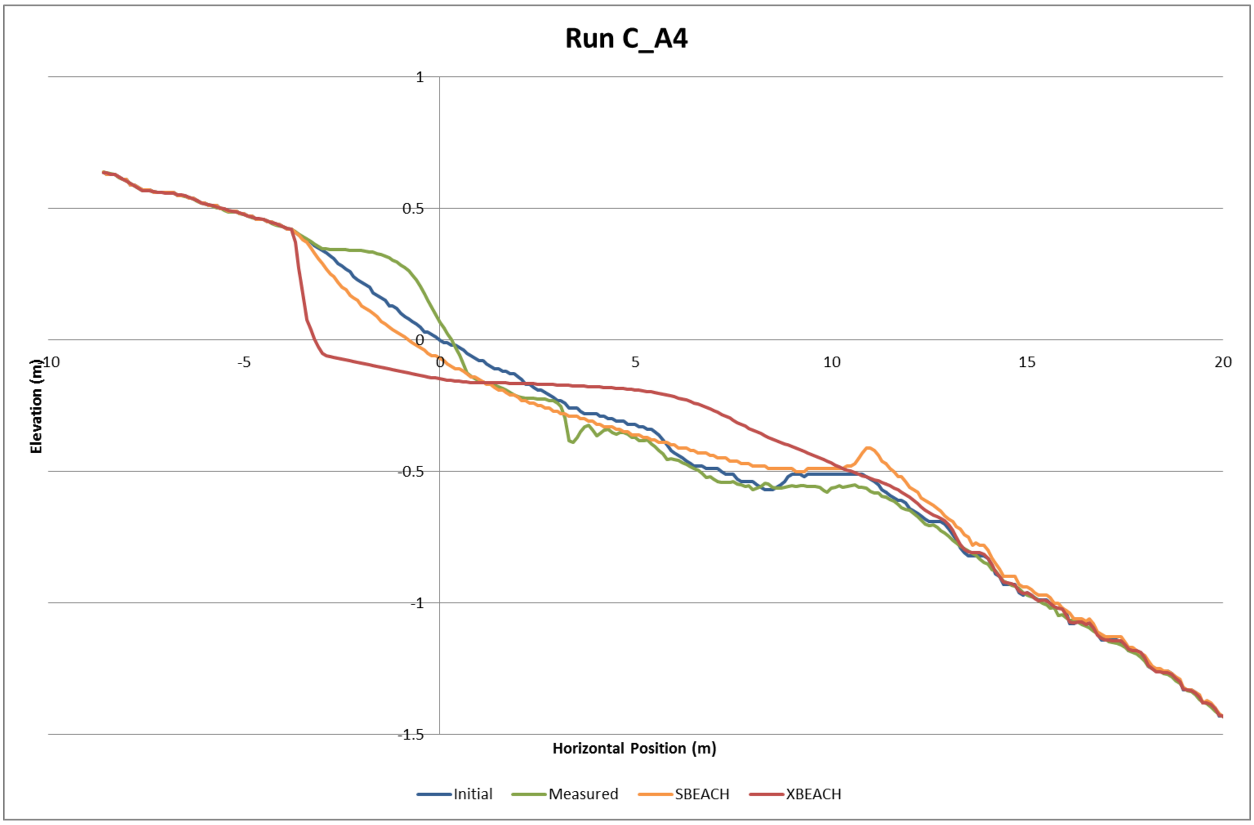
nmeanvar = 3
H
hh
zs

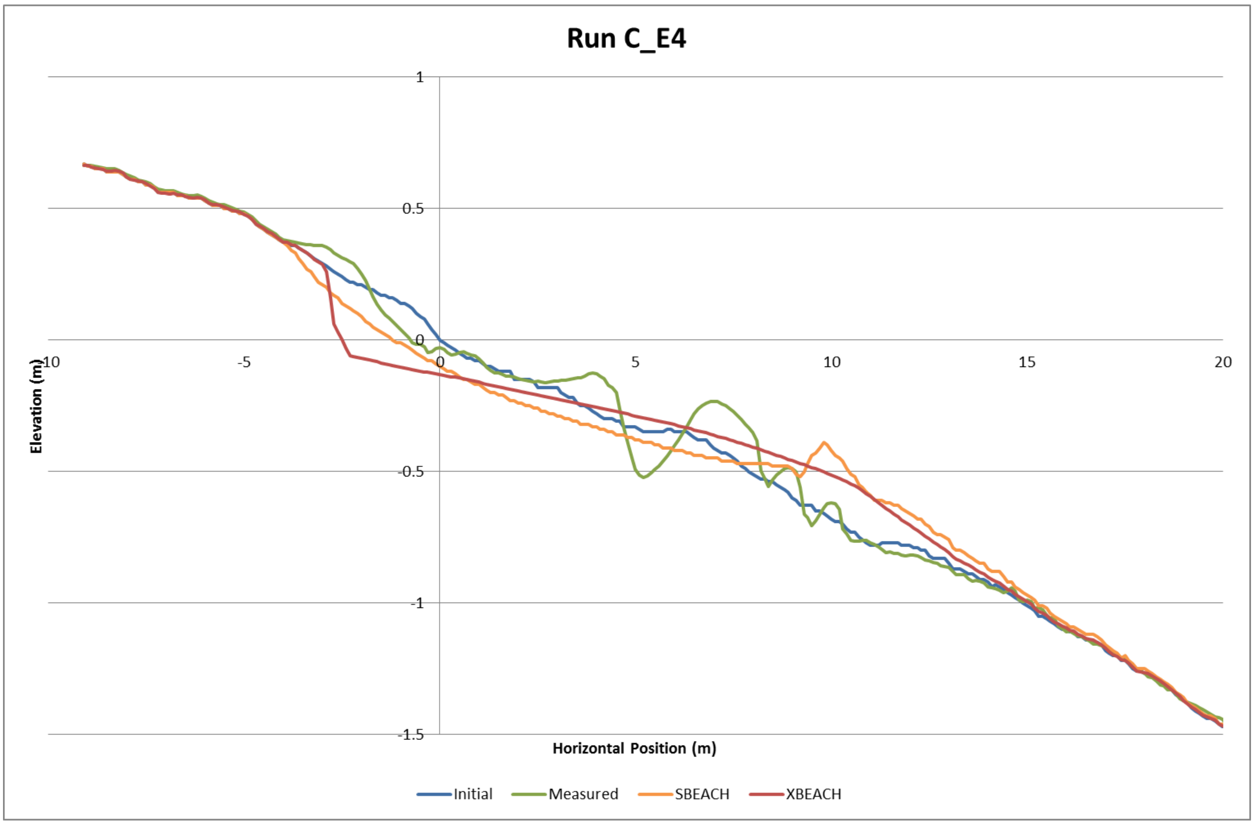
Appendix F-5: Long Wave Accuracy Comparison Parameters

Run	XBEACH			SBEACH		
	BSS	Eroded Volume (m^3/m)	Setback (m)	BSS	Eroded Volume (m^3/m)	Setback (m)
M_A	-3.366	0.513	2.662	-0.003	0.001	0
C_A2	-4.179	0.665	2.759	-0.014	-0.002	0
C_A4	-8.706	0.996	3.179	-1.430	0.253	0.8
B_A1	-7.136	0.592	2.376	-	-	-
B_A2	0.060	0.174	1.269	-	-	-
M_E	-0.701	0.323	1.733	-1.494	0.328	0.9
C_E4	-1.683	0.662	2.497	-1.803	0.429	1.2
B_E1	-2.387	0.249	1.490	-	-	-
B_E2	-0.118	-0.116	1.024	-	-	-

Appendix F-6: Free Long Wave Model Accuracy Runs Output

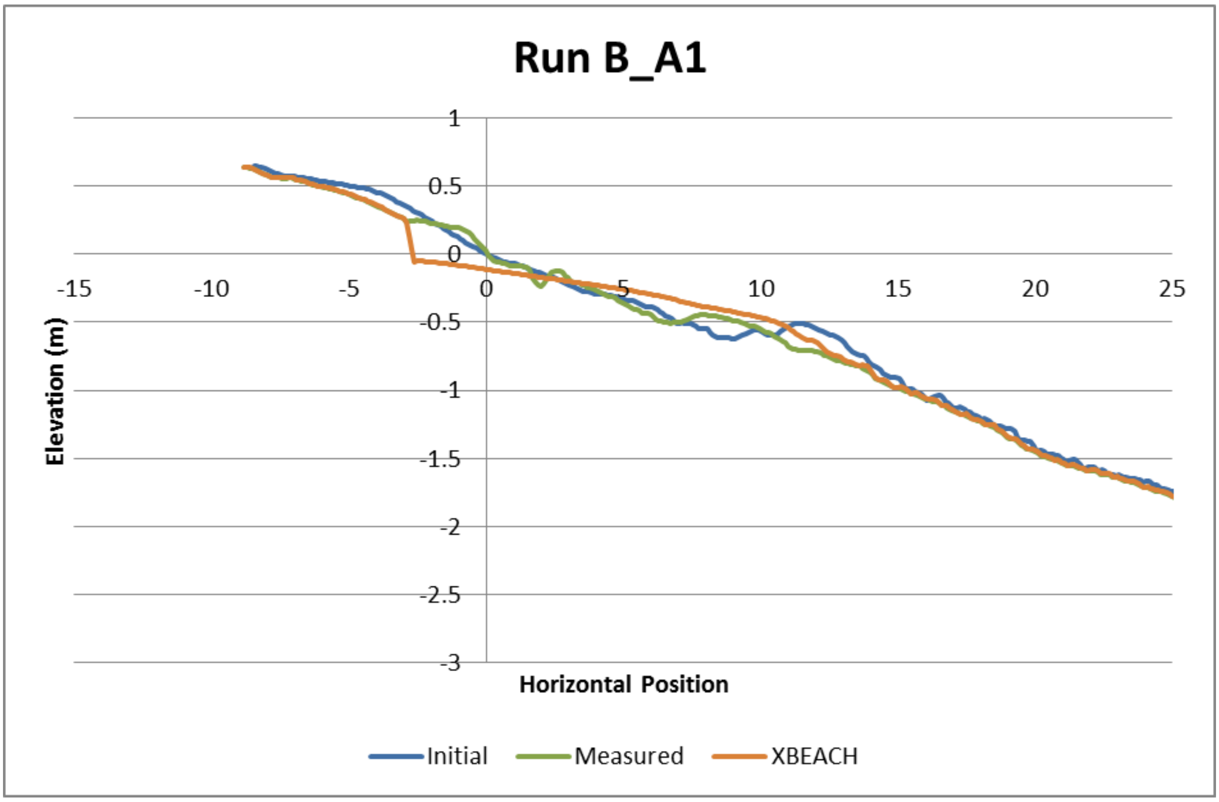


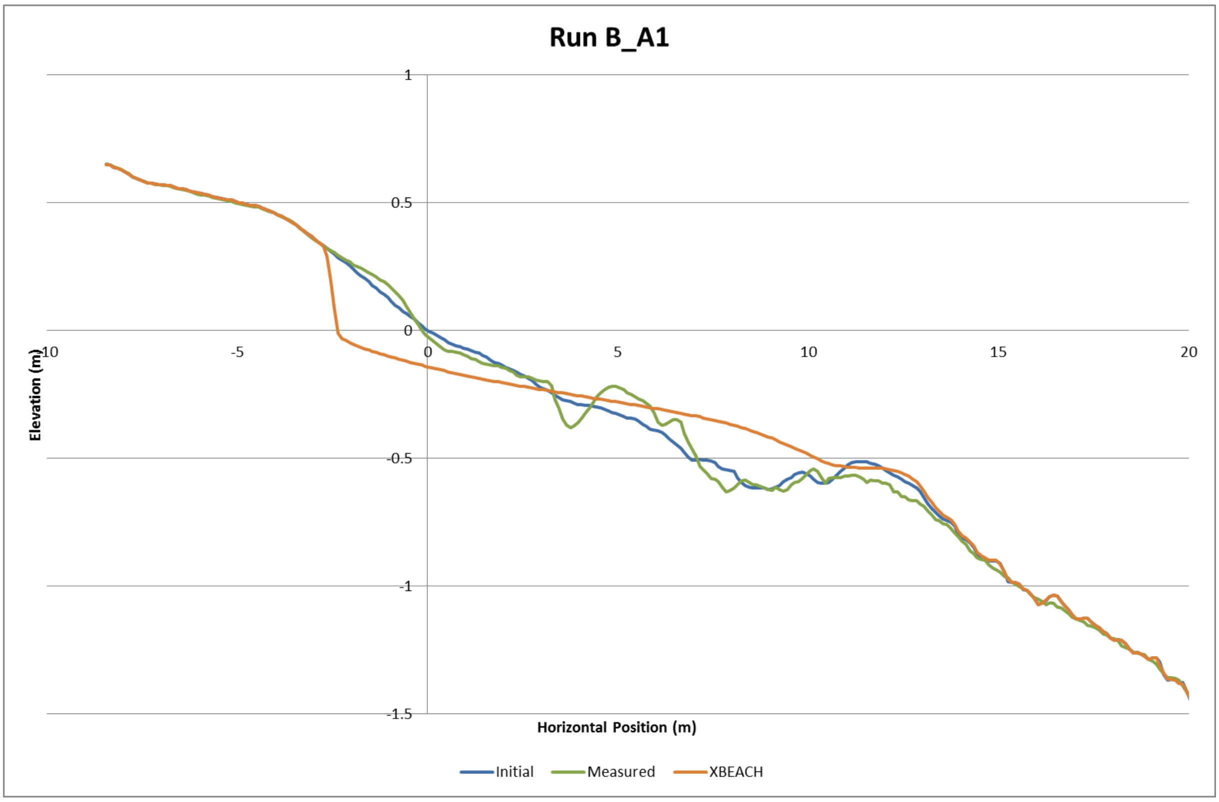


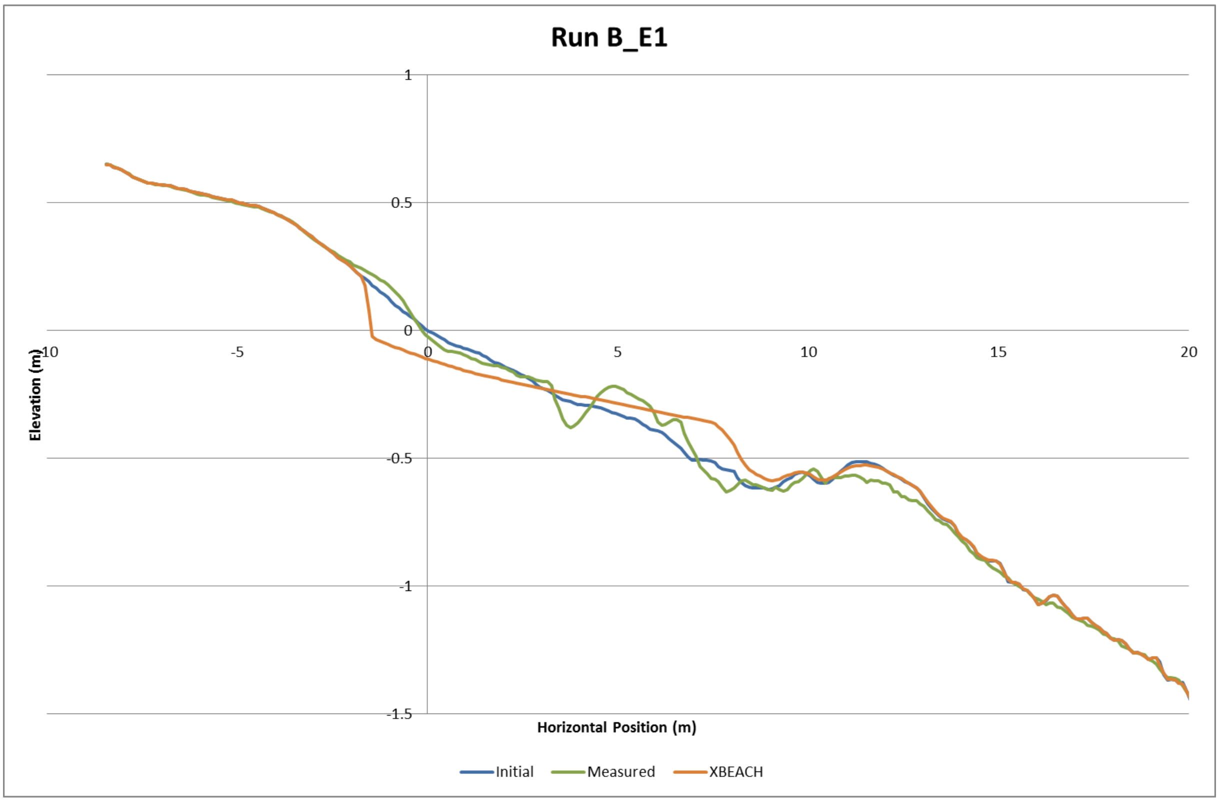


Run C_E4
1
0.5
0
-0.5
-1
-1.5
-10
-5
0
5
10
15
20
Elevation (m)
Horizontal Position (m)
Initial
Measured
SBEACH
XBEACH

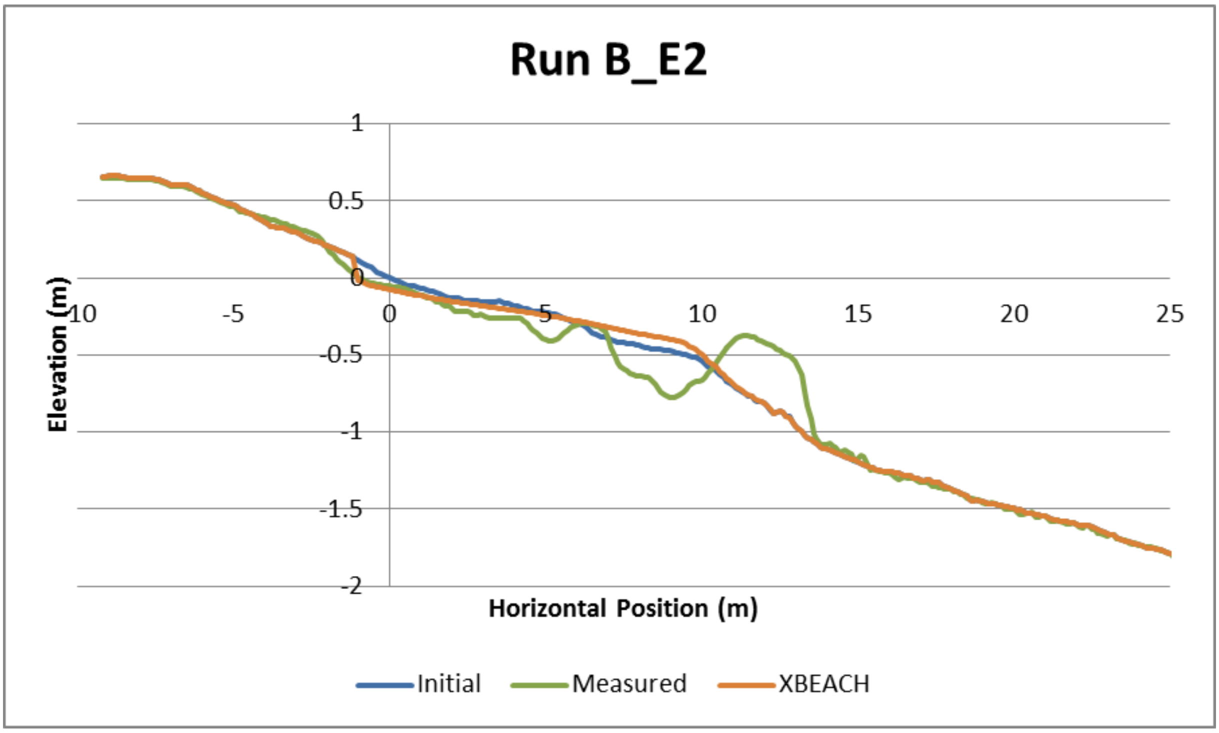
Appendix F-7: Bound Long Wave Model Accuracy Runs Output







Run B_E1
1
0.5
0
-0.5
-1
-1.5
-10
-5
0
5
10
15
20
Elevation (m)
Horizontal Position (m)
Initial
Measured
XBEACH



Run B_E2
1
0.5
0
-0.5
-1
-1.5
-2
-10
-5
0
5
10
15
20
25
Elevation (m)
Horizontal Position (m)
Initial
Measured
XBEACH